INSTITUTE OF PAPER CHEMISTRY

Appleton · Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Five

A Progress Report

to

MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

December 19, 1975

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SUMMARY

Lodgepole pine has a wood specific gravity of 0.39 and an average bark specific gravity of 0.38. Bark extractives levels average 15.7%. Morphologically, the bark contains large numbers of sieve cells, some phellem cells but no fiber. Pulping lodgepole pine bark gave a solids yield of approximately 27%. Screening the bark resulted in 75% of the solids passing through the 100-mesh screen. The fraction retained on the 60- and 100-mesh screens contained 7 grams of sieve cells and <1 gram of phellem cells per 100 grams of bark pulped. Because of the low dormant season adhesion, better-than-average separation through action of the chipper appears likely throughout the year. Hammermilling resulted in a 31% reduction in bark and it is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark and rescreening. Since the bark of the inland form of lodgepole pine is so thin, it is possible that in some instances the bark might not have to be removed.

Ponderosa pine, based upon values in the literature and measurement data from trees sampled as part of the project, has an average wood specific gravity of 0.39 and a bark specific gravity of 0.35. Extractives levels for wood and bark were 5.3 and 15.7%, respectively. Pulping ponderosa pine bark produced a solids yield of approximately 29%. Of this, approximately 12% were sieve cells and 1% were phellem cells. There was no fiber produced. Considering the high extractives and presence of some phellem cells, removal of at least part of the bark appears desirable. Segregation through water flotation is possible but the high moisture contents required do not make the method feasible. The most useful approach appears to be the use of a "screening-hammermilling-rescreening" procedure.

Engelmann spruce has a wood specific gravity of 0.34 and a bark specific gravity of 0.51. Extractives levels were 2.8 and 24.4%, respectively, for the wood and the bark. Morphologically, the bark contains mostly sieve cells and some sclereids. Sieve cells act mainly as filler material and possibly as a bonding material. There are no fibers present in the bark of Engelmann spruce. Pulping Engelmann spruce bark gave a solids yield of approximately 24%. Screening the pulp resulted in 8% sieve cells and 3% sclereids remaining on the 60- and 100-mesh screens. Because of the thin nature of the bark, it is possible that in some instances the bark might not have to be removed. If separation and segregation are desired because of the presence of sclereids and high extractives, several techniques look possible. Wood/bark adhesion is moderate during the dormant season and some separation might be achieved through action of the chipper. The screening-hammermilling-rescreening approach has some merit and it is possible improvements in screening would result in even better segregation. Water flotation also looks promising with segregation possible at moisture contents of 60 to 140%.

Western larch was found to have a wood specific gravity of 0.50 and a bark specific gravity of 0.33. Extractives levels were 1.4 and 14.4%, respectively for the wood and bark. Morphologically, western larch bark does contain a modest amount of sclereidlike fiber. The bark, when pulped, had a solids yield of approximately 28%. Screening the pulp resulted in 11% sieve cells and 1% sclereid-like fibers remaining on the 60- and 100-mesh screens. There are several techniques that appear promising if bark separation and segregation are desired. Dormant season wood/bark adhesion values are low and separation through action of the chipper might be reasonable throughout most of the year. Water flotation segregation looks promising at moisture contents of 60% or greater. Hammermilling resulted in only modest reductions in bark levels but might be combined with screening and/or water flotation as a way of quickly upgrading chip quality.

An added feature of this report is a section giving the Btu, ash, calcium and silica levels for all 20 species investigated thus far.

INTRODUCTION

The paper industry's wood raw material problems are closely tied to the nation's "people" problem. Greater paper and board demands are predicted because of population increases and increases in per capita consumption. Reduced land for the production of wood fiber is closely tied to the increased demand for land by agriculture, recreation, urban sprawl and industrial highway and powerline construction. The need for highly mechanized harvesting systems is in part related to the unwillingness of our present labor force to endure difficult working conditions and spend the long hours required to produce the needed wood raw materials. The people problem has also manifested itself in the increased environmental awareness which, because of the emotional issues involved, is rapidly forcing the harvesting of forest products using less than optimum operating procedures.

Interestingly, two of the most promising approaches for increasing our total fiber supply include increased use of forest logging residues and the use of short-rotation forestry. Use of forest residues provides an immediate per acre increase in wood production through the use of wood normally left in the woods, while short-rotation forestry involves the use of rapidly-growing species and the employment of such intensive forest management techniques as fertilization, irrigation and complete tree utilization to maximize production. Equally interesting is the realization that the success of both of these two approaches hinges on adequately handling the bark problems that are associated with improved utilization.

The objective of Project 3212 is to adequately identify the industry's bark problem and make it possible for the pulp and paper industry to take advantage of whole-tree chipping techniques and the promising short-rotation forest management systems being developed. To date, the bark properties of 16 important pulpwood species have been investigated. Progress Report Five presents a comprehensive characterization of the bark of four western species including lodgepole pine, ponderosa pine, western larch and Engelmann spruce. The importance of recovery boiler scaling problems and increased interest in the use of bark for fuel has prompted us to add ash content and bark fuel value to the list of information required for each pulpwood species. Included in the report that follows is information on the ash content and fuel value of the first twenty species investigated.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

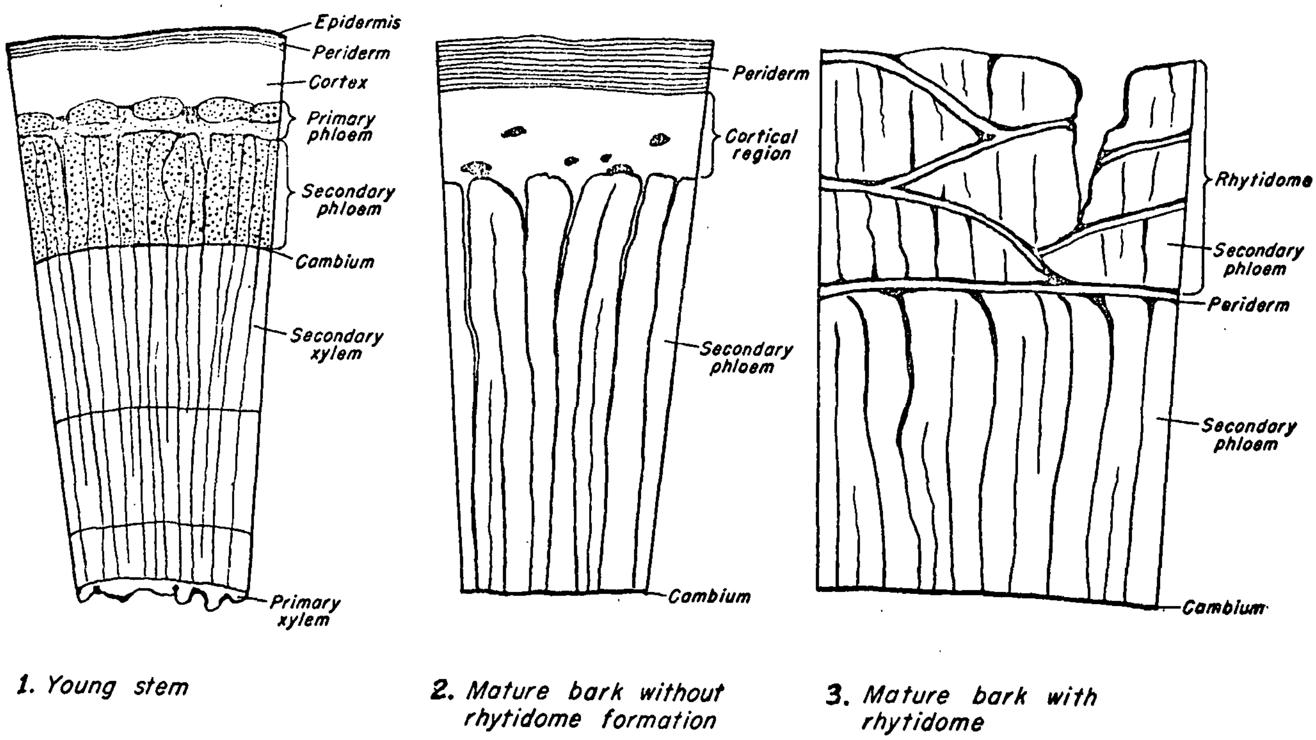


Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch of Stem. (2) Cross Section of Bark Having Persistent Cortex, such as that in the Middle-Aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later morphological examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(c \cdot d)/[c-(b-a)]$ where:

a = weight of pycnometer + heptane

b = weight of pycnometer + heptane + chip

c = weight of chip (wet — before being placed in heptane)

d = density of heptane.

BARK AND WOOD PROPERTIES OF LODGEPOLE PINE
(*Pinus contorta* Dougl.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Lodgepole pine, one of the most widespread conifers in western North America, grows from southeastern Alaska and the interior Yukon Territory south to northern Baja California and east to the Black Hills of South Dakota. Two main varieties of this pine are often distinguished; the coastal type, low and scrubby, grows along the Pacific coast, and the inland form, generally found in mountainous regions, is taller and more commercially important. This species grows on a wide variety of soils, elevations and terrain. Frequently found in areas too poorly drained to support other local species, lodgepole pine grows best in moderately acid, sandy or gravelly loams, moist, light and well-drained. Altitudes vary from sea-level with the coastal form to 11,500 ft for the inland type. Growth rate, size and life span vary greatly with elevation and site. Mature coastal form trees range from an extreme dwarf size of 2-5 ft, to 20-40 ft in height. The inland form of lodgepole pine reaches heights of 60-80 ft and diameters of 7-13 inches at 140 years.

WOOD AND BARK MORPHOLOGY

Wood

The wood of lodgepole pine is moderately light, generally straight but uneven-grained and medium-fine textured. The sapwood is narrow, nearly white to pale yellow and the heartwood, indistinct and slightly darker in color. Growth rings are distinct, delineated by a band of darker latewood. The transition from early- to latewood is more or less abrupt and the earlywood zone is wide or narrow. Lodgepole pine fibers or tracheids average 35-45 µm in diameter and 3.1 mm in length. Rays are very fine on the cross section and are not visible to the unaided eye. Ray tracheids are present in both the uniseriate and fusiform rays. The uniseriate rays are numerous, 1-8+ cells in height. Fusiform rays are scattered, 2-3 seriate through the central thickened portion and up to 30+ cells in height. Rays occupy approximately 5.7% of the total wood volume. Resin canals, lined with thin-walled epithelium, are frequently occluded with tylosoids in the heartwood. The longitudinal resin canals have a maximum diameter of 110 µm and the transverse canals, associated with the fusiform rays, are less than 50 µm in diameter.

Bark

Lodgepole pine grown in the coastal region has thick bark, up to 1 inch, deeply furrowed and transversely fissured, and reddish-brown in color. The inland or mountain form tree has thinner bark, usually about 0.2 inch thick, which is scaly and yellowish-brown in color. The outer bark usually shows narrow rhytidome layers with thin periderms contrasting with a narrow inner bark of finer texture and lighter-colored secondary phloem. The thin bark makes the lodgepole pine highly susceptible to fire kill. In the inland form used in this study, the outer bark accounted for approximately 80% of the total bark thickness by weight. Figure 2 illustrates a cross section of inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

Bark structure of the young lodgepole pine is quite similar to jack pine. The periderm is composed mainly of thin-walled phellem cells with a few alternating layers of thick and thin-walled cells developing within 5 years. The cortical region is broad with large resin canals and the secondary phloem has the basic pattern of parenchyma, sieve cells and narrow rays.

In the mature tree, the periderm, which is formed rather close to the cambial region, consists of a layer of phellogen, 2-3 layers of phelloderm and 5-10 layers of phellem. Peridermal cells are rectangular in shape on cross and radial sections, 30-50 μm in tangential diameter and 20-30 μm in radial diameter on cross section. Phelloderm cells are parenchymatous in nature and often contain "resinous" substances and small crystals.

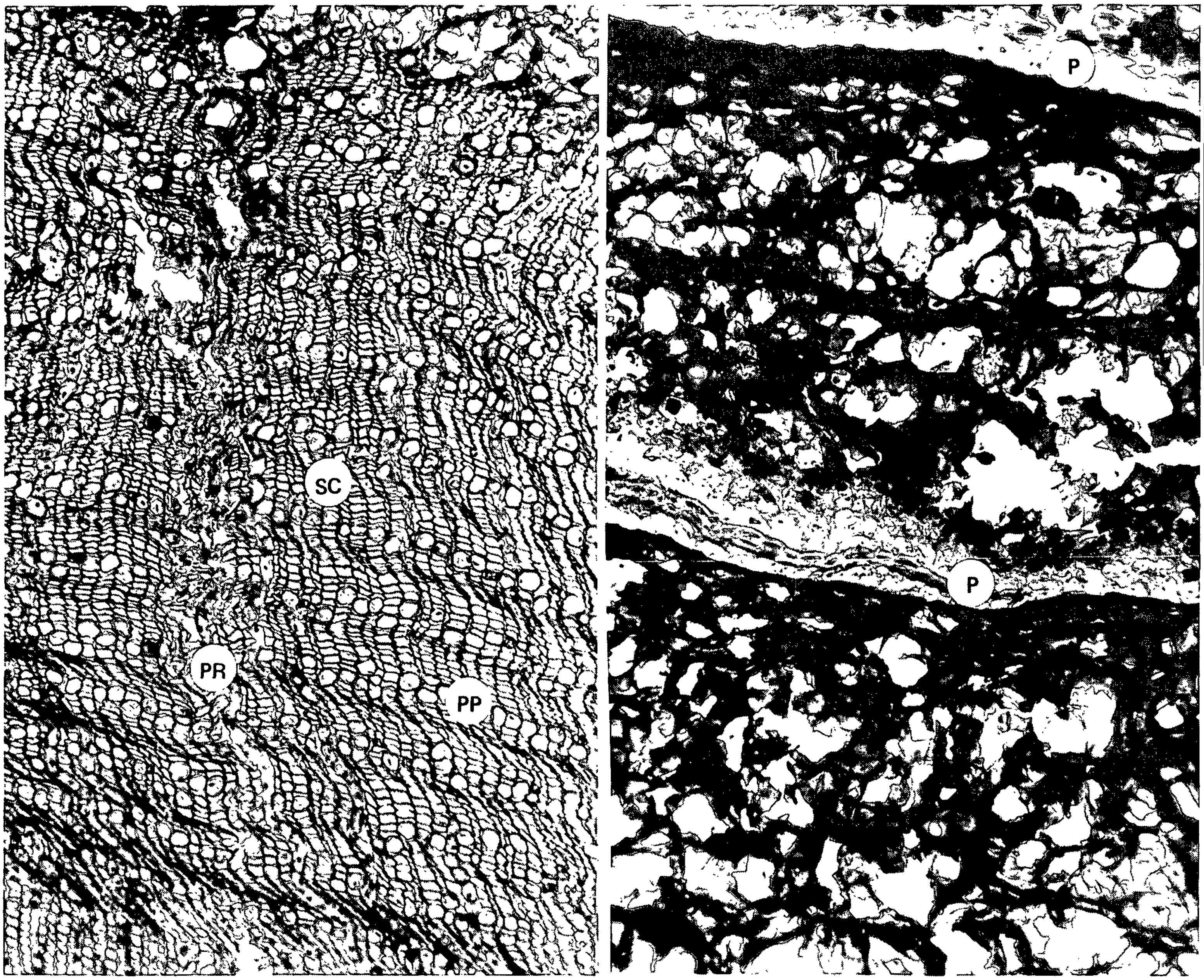


Figure 2. Cross Section of Lodgepole Pine. Photomicrograph on Left Shows Cross Section of the Inner Bark Close to the Cambial Region. Illustrated are Sieve Cells (SC), Discontinuous Tangential Lines of Phloem Parenchyma (PP) and Phloem Rays (PR). Photomicrograph on the Right is a Cross Section of the Outer Bark Showing Periderm (P) Layers. Magnification — 75X

The narrow inner bark or secondary phloem of the lodgepole pine is composed of sieve cells, sporadically distributed parenchyma and uniseriate and fusiform phloem rays. Sieve cells are rectangular on cross section, usually 20-30 μm in tangential diameter and 10-25 μm in radial diameter, varying from 2.2 to 4.4 mm in length (1). Sporadic parenchyma cells in discontinuous lines interrupt the radial alignment of every 5-10 sieve cells. Individual parenchyma cells are about 100-250 μm in height and contain styloid crystals about 50 μm long. Parenchyma strands are about the same length as the adjacent sieve cell. Albuminous or erect ray cells, 2-3 times the height of ordinary ray cells, are present and conspicuous in almost every ray close to the cambium. Uniseriate rays are usually 6-10 cells or 200-300 μm high on tangential section. Rays often become dilated at the outer bark, especially fusiform rays which contain resin canals, sometimes 2-3 in the same ray. Canals, formed by 3-4 thin-walled epithelial cells at the inner border, often enlarge to a diameter of 1.5 mm. All secondary phloem tissues become much expanded or deformed in the transformation to the outer bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

Specific Gravity

Table I summarizes the information available on wood and bark of lodgepole pine. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of lodgepole pine at several moisture contents.

TABLE I

LODGEPOLE PINE SPECIFIC GRAVITY INFORMATION
(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
0.38						Besley (U.S.) (3)
0.38	0.26-0.55					Maeglin & Wahlgren (4)
0.39	0.32-0.49					Tackle (5)
0.38						IUFRO (6)
0.38						Isenberg (7)
		0.34	0.51			Smith & Kozak (8)
0.40 (sapwood) 0.43 (heartwood)		0.38	0.33	0.35		IPC 3212-73
0.40 (sapwood) 0.40 (heartwood)		0.25	0.51	0.40		IPC 3212-76
0.43[a]						Isenberg (7)
				0.60[a]		Harkin & Rowe (9)

[a]Ovendry weight/ovendry volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.39 appears appropriate for the wood of lodgepole pine. Our limited data show the heartwood and sapwood to be very close in specific gravity.

The specific gravity of the total (inner + outer) bark of lodgepole pine is also very close in specific gravity to that of the wood. The inner bark of 3212-73 was higher in specific gravity than the outer bark while the reverse was true for 3212-76. The barks of these two trees were also quite different with 3212-73 having a much thicker bark than 3212-76. This might be due to the difference in geographic location and/or altitude between the two trees, Idaho vs. British Columbia. Overall values suggested for use in species comparisons are 0.39 for wood and 0.32, 0.45 and 0.38 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

It appears that, for between-species comparisons, an extractives level of 3.5% is appropriate for the wood of lodgepole pine. The extractives content of lodgepole pine bark apparently varies from source to source (and very likely seasonally). Averaging the four IPC values gives an alcohol-benzene extractives level of 15.7% which is probably a reasonable figure to use. The value given by Harkin and Rowe in Table II appears abnormally high and was not used in figuring the average. The value of 15.7% also appears correct when it is compared to the jack pine value of 15.3%. The two species are very similar in appearance, hybridize where their ranges overlap and should have similar extractives levels. This relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques. Extractives in pines are one of the causes of color reversion in mechanical pulps and can cause problems when the sulfite process is used (10).

TABLE II

LODGEPOLE PINE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	3.5	Fengel & Grosser (11)
Wood	3.5	Isenberg (7)
Wood	3.5	Rydholm (12)
Bark	39.6	Harkin & Rowe (9)
Bark	17.0	IPC 3212-73
Bark	12.0	IPC 3212-76
Bark	23.6	IPC 3212-81
Bark	10.3	IPC 3212-89

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of lodgepole pine having an effect on the pulp are sieve cells. Chang (1) estimated that 78.2% of the tissue elements in the inner bark are sieve cells. There are no true fibers in the bark of lodgepole pine.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

There is also a minor amount of thick-walled, cogwheel-shaped phellem cells in lodgepole pine similar to those found in the southern pines but fewer in numbers. Most of these cells, however, would be lost in the washing and cleaning operations. Under typical kraft pulping (48-52% yield), phellem cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high-yield pulping, many of these phellem cells could remain in clumps and cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, spruce).

As a check on pulp yield and the nature of the material produced from lodgepole pine, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation.

TABLE III

LODGEPOLE PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-73	Sample No. 3212-76	Remarks
Yield, % solids	15.3	39.6	
Fraction			
On 60 mesh, %	21.9	23.8	The furnish contained principally sieve cells (95+%) with a small percentage of thick-walled cogwheel-shaped phellem cells (<5%) and a trace (<1%) of parenchyma and thin-walled paridermal cells. The average arithmetic length of the sieve cells contained in the fraction was 1.63 mm (range 0.3-3.5 mm)
On 100 mesh, %	3.8	7.8	The fraction contained principally sieve cells (90+%) with small percentages of thick-walled cogwheel-shaped phellem cells (<5%) and thin-walled parenchyma and peridermal cells (<5%)
On 150 mesh, %	5.6	10.2	The fraction contained parenchyma and thin-walled peridermal cells (50-60%), sieve cells (20-30%) and thick-walled cogwheel-shaped phellem cells (10-20%)
On 200 mesh, %	5.6	6.8	The fraction contained principally parenchyma and thin-walled peridermal cells (80-90%), with small percentages of thick-walled cogwheel-shaped phellem cells (10-20%) and sieve cells (<5%)
Through 200 mesh, %	63.1	51.4	The fraction contained a large percentage of parenchyma and thin-walled peridermal cells (70-80%) with thick-walled cogwheel-shaped phellem cells (20-30%) and a trace (<1%) of sieve cells

[a]Percentages given are on a dry weight basis.

Micropulping of lodgepole pine bark resulted in a yield of 15 to 40% solids. The wide range in yields was probably due to the major differences in the barks of the two trees pulped. Tree 3212-73 had a much thicker bark and higher percent outer bark than 3212-76. When screened, the coarse screens (60 and 100-mesh) retained most of the sieve cells and a minor amount of phellem cells. The on 150-mesh screen retained mostly parenchyma and thin-walled peridermal cells with minor amounts of sieve cells and phellem cells. The on 200-mesh and through 200-mesh screens contained principally parenchyma and thin-walled peridermal cells and a small amount of phellem cells. Figure 3 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, an average of 27 grams of solids will result. Of this 27 grams, about 7 grams (7%) of sieve cells and <1 gram (1%) of phellem cells will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

Auchter (13) and Horn and Auchter (14) investigated the feasibility of pulping chips containing approximately 10% bark of a number of western species including lodgepole pine. They found that 0.2% more active cooking chemical as caustic soda and 0.2% more chlorine to bleach was needed for chips containing bark. Dirt levels could be lowered to an acceptable level by more efficient use of a centricleaner system and presence of bark in the pulp did not affect strength properties. Although digester yield from rough wood was less, the net gain per rough cord would be at least 4% higher for unbarked chips. They also felt that another 5-10% gain in yield could be realized because there would not be the wood

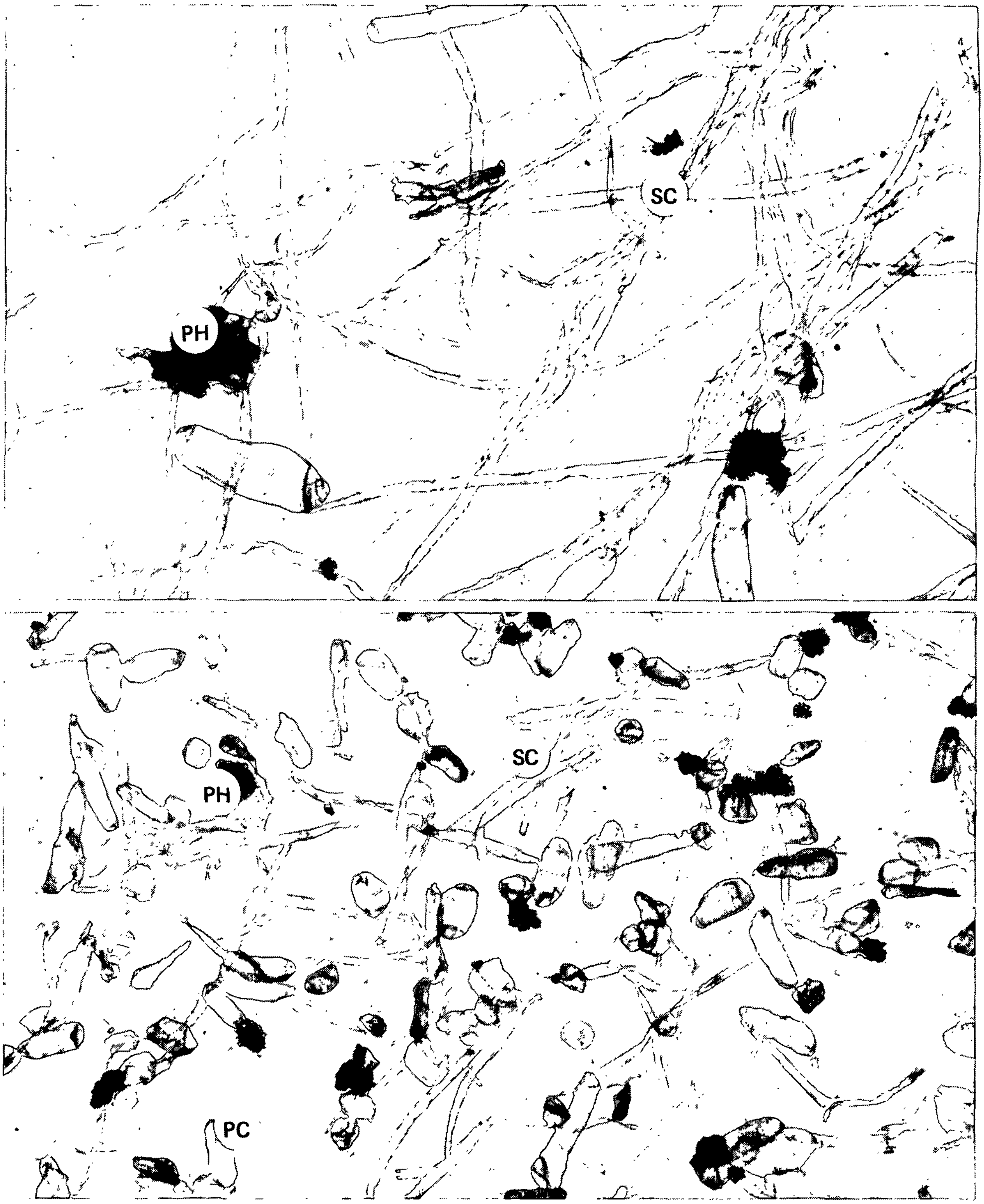


Figure 3. The 60-Mesh Screen (Top) Contained by Weight Principally Sieve Cells (95+%). The 150-Mesh Screen (Bottom) Contained Parenchyma and Thin-Walled Peridermal Cells (50-60%) with Smaller Percentages of Sieve Cells (20-30%) and Phellem Cells (10-20%). Magnification 75X. Symbols Illustrate Sieve Cells (SC), Parenchyma and Peridermal Cells (PC) and Phellem Cells (PH)

loss usually incurred during barking. In our opinion, the net gain of 4% per rough cord would consist mainly of the less useful sieve cells.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for lodgepole pine samples collected July 8 (growing season) and October 12 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figures 4 and 5 illustrate the zone of failure for lodgepole pine during both the growing and dormant seasons. During the growing season, wood/bark adhesion was low (2.2 kg/cm^2) and the failure zone was located between cells in the cambium zone immediately adjacent to the last-formed xylem cells. It is worth noting that the tree examined (from British Columbia) is a very slow-growing tree and the last 4-5 growth rings are only 5-6 cells in width (see photomicrographs). The current growth ring is considered to be complete and the cambium is in, or close to, a state of dormancy. During the dormant season, wood/bark adhesion increased to 5.6 kg/cm^2 and the failure zone was located in the secondary phloem between sieve cells and phloem parenchyma located approximately 0.6-0.8 mm from the cambium zone.

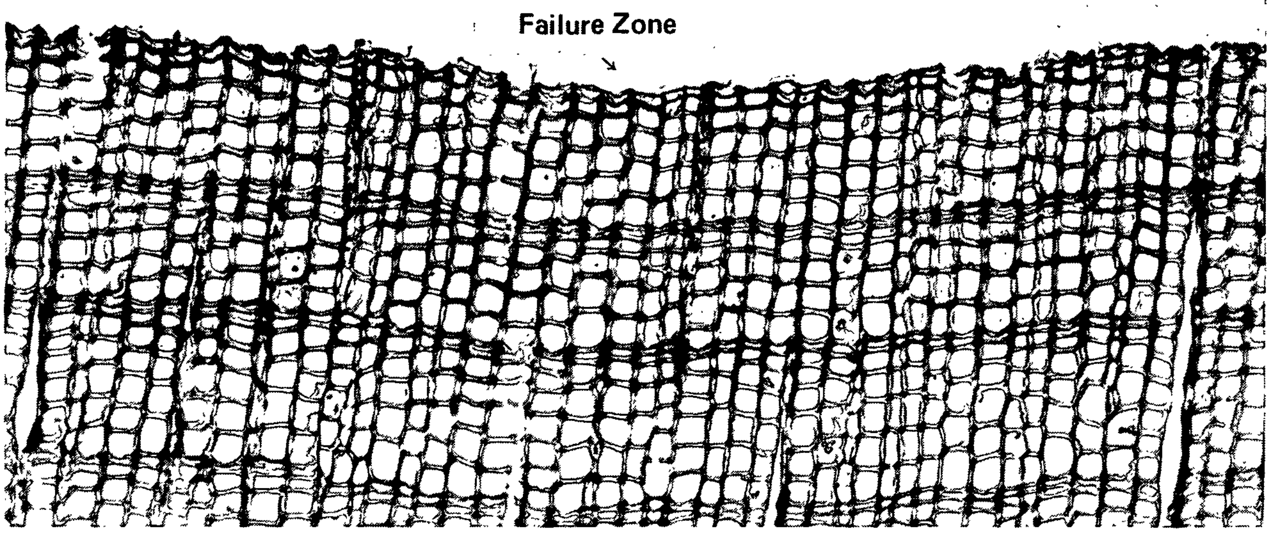


Figure 4. Illustrated is the Lodgepole Pine Growing Season Failure Zone. The Failure Zone was Located Between Cells in the Cambium Zone Immediately Adjacent to the Last-Formed Xylem Cells. Magnification — 125X

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids or phellem cells and a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips).

Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

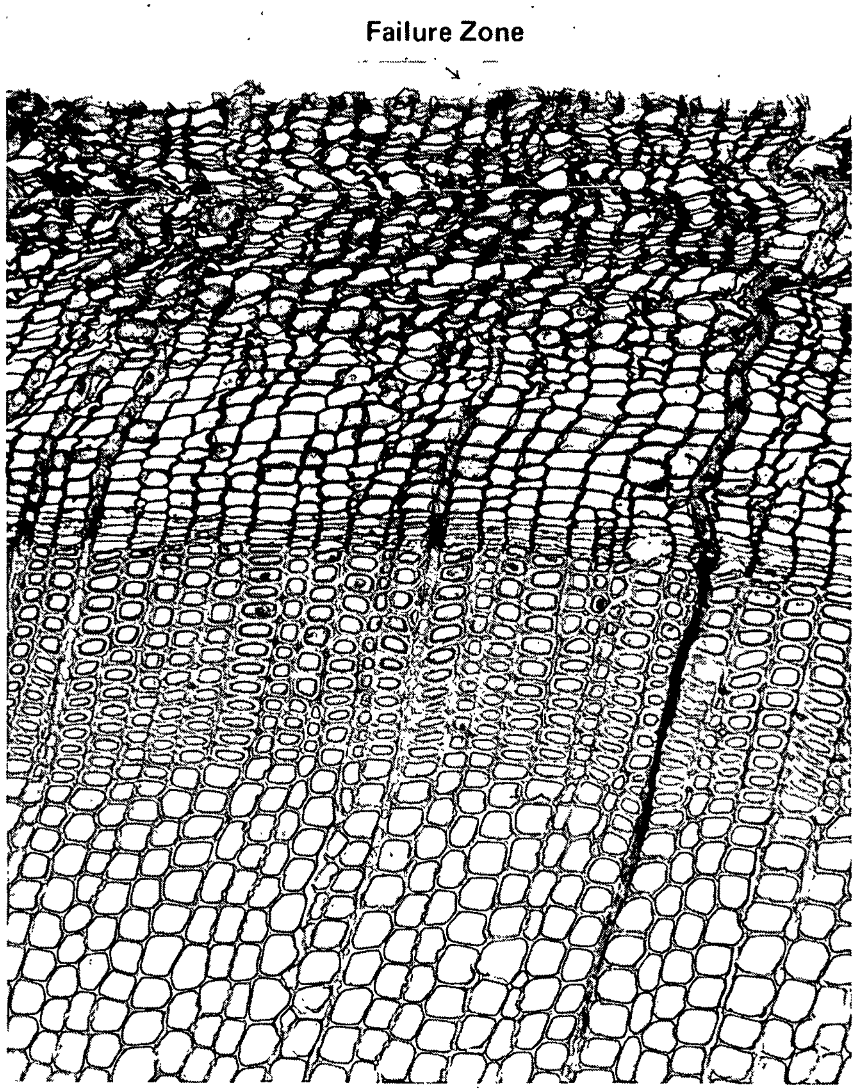


Figure 5. Illustrated is the Dormant Season Failure Zone for Lodgepole Pine. Failure Occurred in the Secondary Phloem Between Sieve Cells and Phloem Parenchyma. Magnification — 125X

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of lodgepole pine.

Outer bark strength values for lodgepole pine were low compared to other softwoods tested thus far. No test was obtained for inner bark because of its thinness. The toughness values for wood were relatively low although considerably greater than the bark values. The low toughness values obtained for wood make it appear that hammermilling or a similar technique might not work well on this species. The low toughness and strength values for the bark are probably related to the lack of fiber and high percentage of sieve cells in lodgepole pine.

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF LODGEPOLE PINE[a]

Material	Strength	Toughness
Wood	--	0.28
Inner bark	--[b]	0.10
Outer bark	2.4	0.08

[a]Determinations average of two different trees except inner bark strength which is based on one tree.
[b]Too thin to test.

Toughness tests on a number of species, as reported by Wood Handbook (15), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test is done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. In a green condition Wood Handbook results show lodgepole pine wood with a tangential value of 210. In comparison, at 11-12% moisture content, values for loblolly pine were 260, slash pine — 320 and jack pine — 240. Our results also indicate that lodgepole pine wood is not as tough as the wood of these other species. When enough data are obtained, correlations will be run between IPC toughness values and hammermilling results.

Summarized in Table V are the results of the hammermilling tests run on lodgepole pine wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a modest reduction in levels of bark. When the half-sized chips for the two trees investigated

TABLE V

SUMMARY OF HAMMERMILLING TEST ON LODGEPOLE PINE

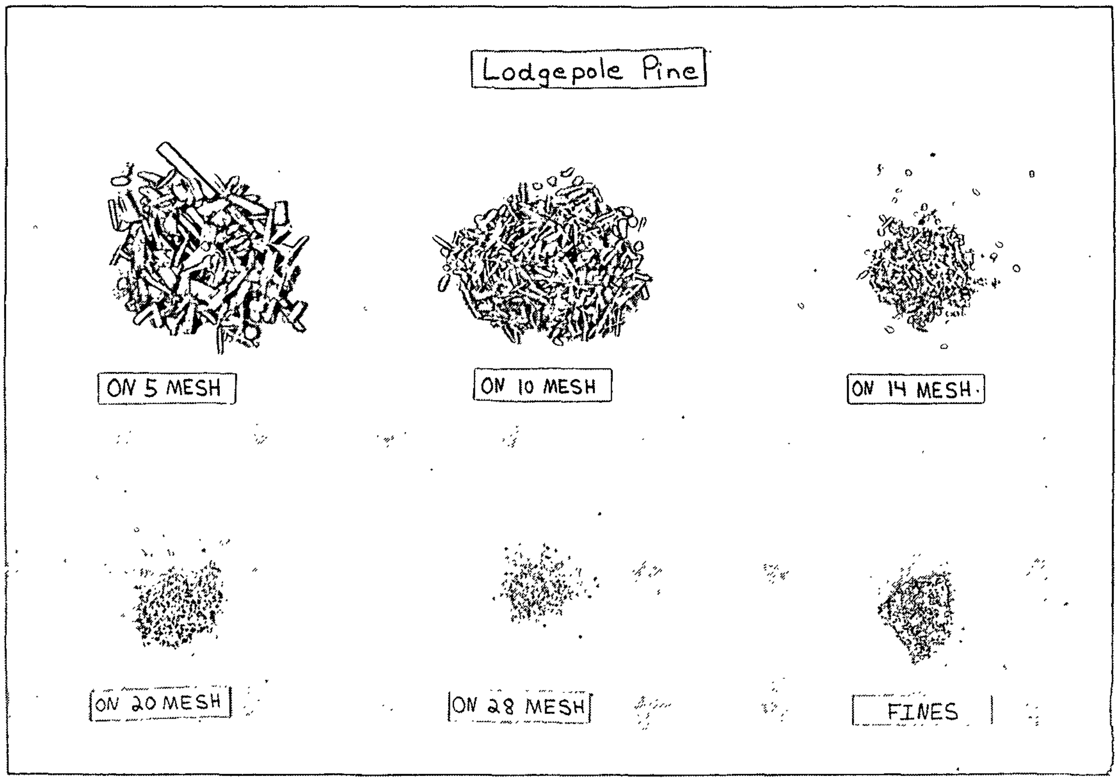
Tree No.	Material	Fraction Retained on Standard Screen, %[a] 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-73	Bark	14	32	20	8	10	16	Inner bark very thin and seems to stay attached to outer bark
	Sapwood	65	26	4	1	1	2	
	Heartwood	63	28	6	2	1	2	
3212-76	Bark	21	35	17	7	7	14	Inner bark very thin and seems to stay attached to outer bark
	Sapwood	59	29	7	2	1	2	
	Heartwood	56	32	6	2	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

were hammermilled and the material on the 14-mesh screen retained, the result was a 4% loss in wood and a 31% reduction in bark. These results are intermediate compared to other softwoods tested thus far, confirming results obtained from the toughness tests. A much larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss is also more than doubled (50% bark removal and 11% wood loss). This additional 7% loss in wood might be acceptable in view of the increased amount of bark removed and fuel value of the wood. Figure 6 illustrates the effect of hammermilling on wood and bark of lodgepole pine. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 6 (16, 17). Summary Table XXVII compares bark strength, toughness and reaction to hammermilling of lodgepole pine to other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.



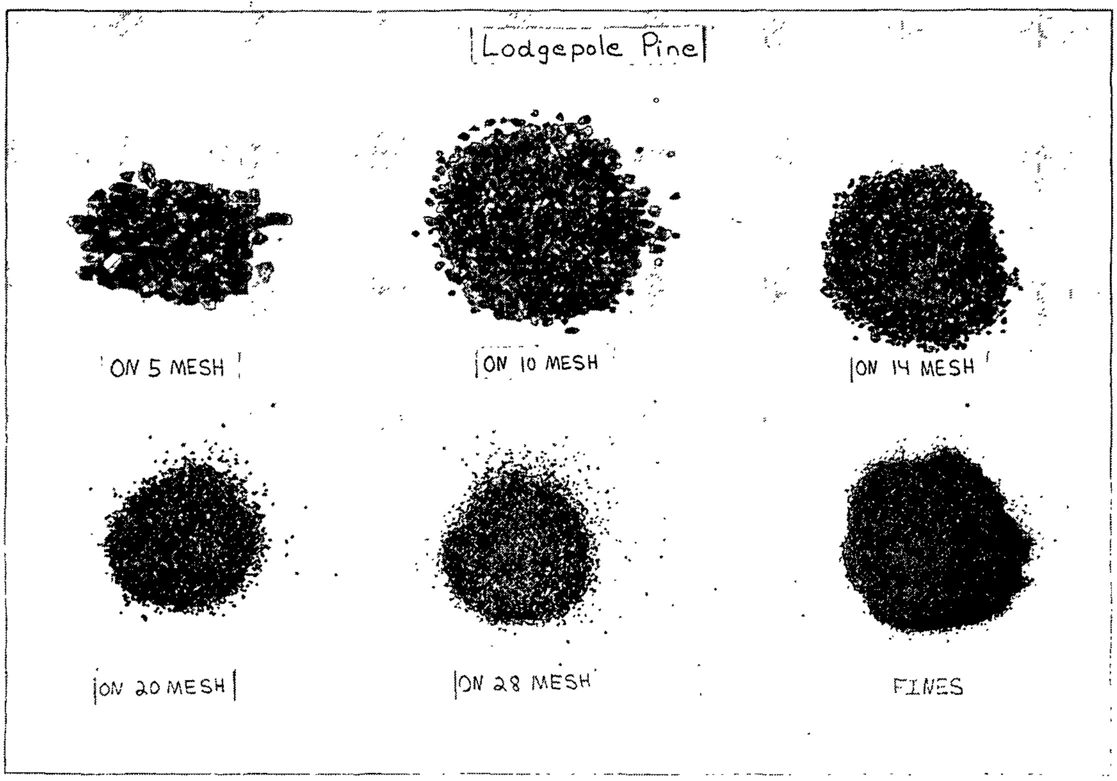


Figure 6. Illustrated is the Effect of Hammermilling on Lodgepole Pine Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two lodgepole pines (IPC 3212-73 and IPC 3212-76) were used in making the original determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested.

After the data from the two trees were tabulated and plotted, it was found that they behaved very differently. Bark densities for the Idaho tree, 3212-73, were the same or slightly lower than wood densities at the same moisture content. The British Columbia tree, on the other hand, had higher bark densities than the wood at the same moisture content. Density determinations were partially rechecked using another tree from British Columbia and trends were the same for this tree.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Illustrated in Fig. 7 is the relationship that was found between moisture content and density for the Idaho tree, 3212-73. Figure 8 illustrates the relationship that was found between moisture content and density for the two British Columbia trees, 3212-76 and 3212-89. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate segregation might be possible for the thicker-barked Idaho tree at moisture contents of between 130 and 170%. No segregation would be possible for the thinner-barked British Columbia trees. Both bark and wood would float up to moisture contents of about 110% and, after that, densities are too close at similar moisture contents. It is interesting to note the relationship between wood and bark densities at various moisture contents for the two curves. Bark densities were consistently lower than wood densities for the Idaho tree while bark was higher than wood up to about 120% moisture content for the British Columbia trees.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink.

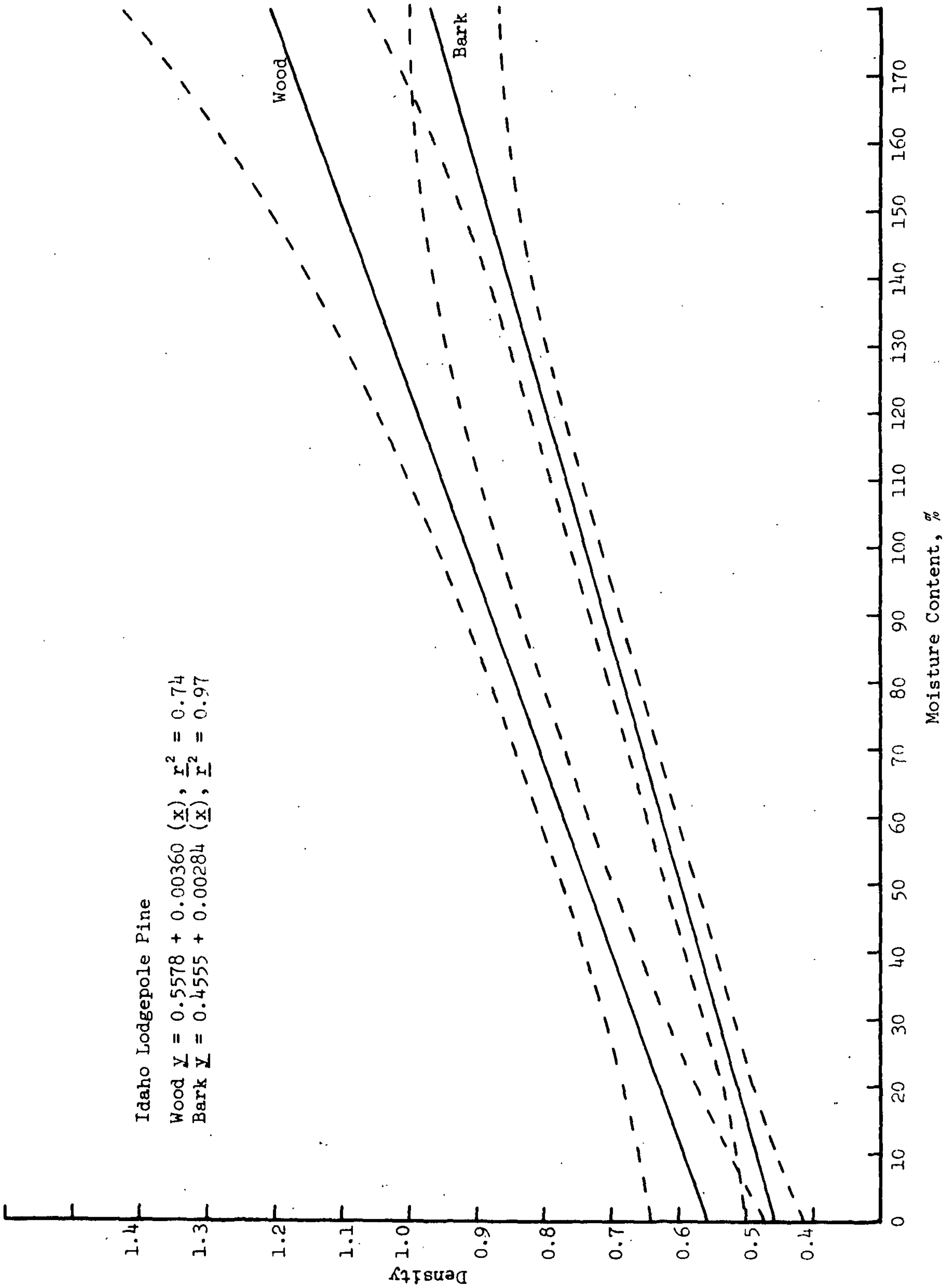


Figure 7. Illustrated is the Relationship Between Basic Density and Moisture Content for Lodgepole Pine from Idaho. The Dashed Lines are Two Standard Deviations Above and Below the Mean

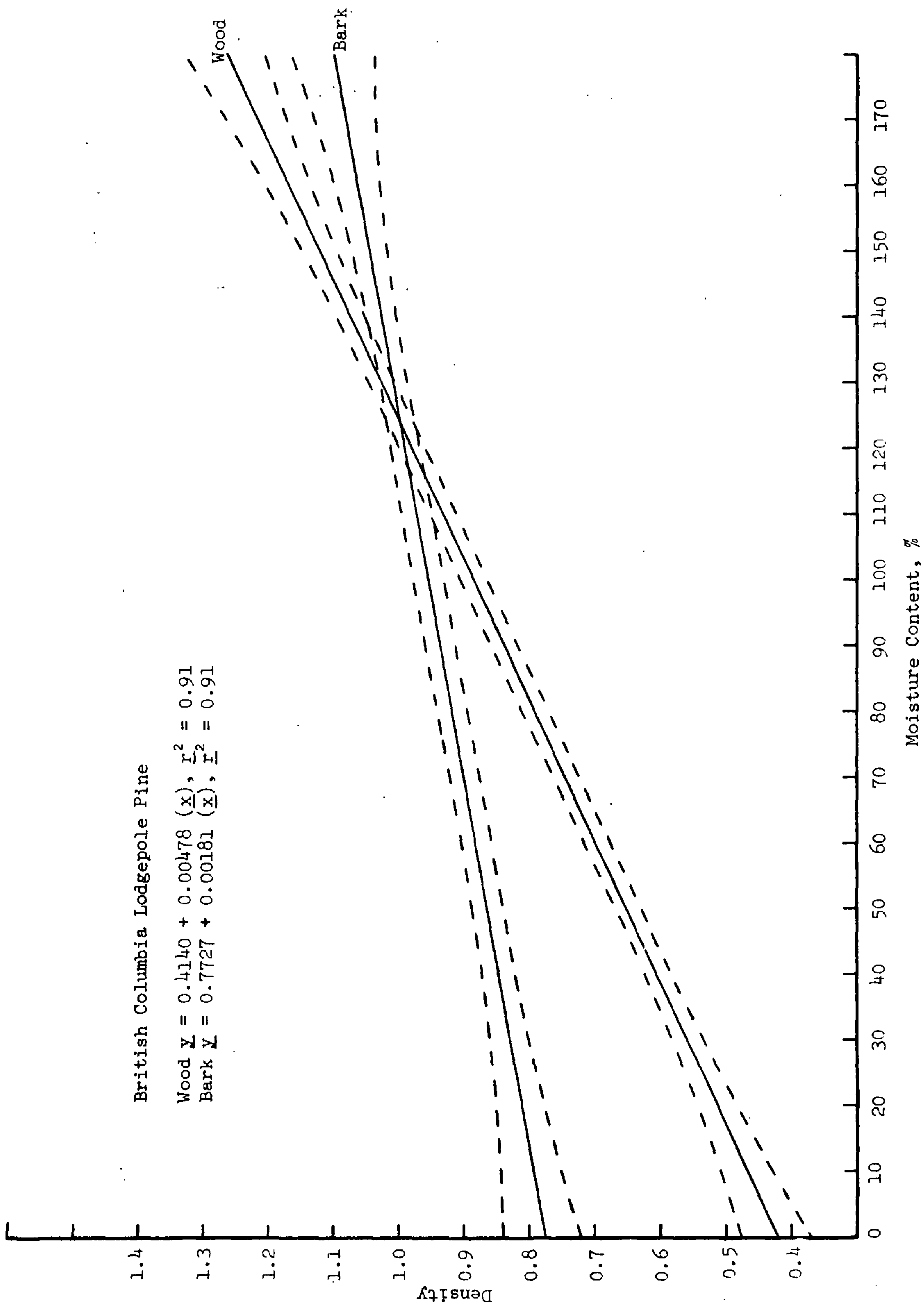


Figure 8. Illustrated is the Relationship Between Basic Density and Moisture Content for Lodgepole Pine from British Columbia. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for lodgepole pine. These results agree with the results obtained in the density determination measurements for both the Idaho and British Columbia trees which showed both wood and bark floating at 20% moisture content.

DATA INTERPRETATION

Lodgepole pine, like most of the softwoods investigated thus far in the project, has no fiber in the bark. It does contain sieve cells which would act as filler in paper but would probably not contribute to paper properties. It also contains a minor amount of phellem cells, most of which would be lost during pulping. However, in high-yield pulping, clumps of phellem cells could cause problems such as "fisheyes" in paper. For every 100 grams of bark that is pulped, about 7 grams of sieve cells and <1 gram of phellem cells will be produced.

Extractives in lodgepole pine bark are fairly high and this, coupled with the lack of fiber, probably makes removal of at least part of the bark desirable. In IPC tests, dormant season adhesion values were low and better-than-average separation through action of the chipper might be able to be achieved. The species was intermediate in reaction to hammermilling. This method,

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR LODGEPOLE PINE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-73	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-73	After 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-73	After 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-76	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-76	After 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-76	After 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

combined with screening, might be a way of quickly upgrading chip quality. Involved would be screening, hammermilling the fractions high in bark and rescreening. Use of this method has the advantage of producing a reject material that could be used as fuel. Segregation by water flotation appears possible for some trees but the high moisture content required and the uncertainty as to whether the technique would work make this method less desirable. The bark of the inland form of lodgepole pine is thin, suggesting that, because of the low percentage of bark, it may be possible in some instances to either not remove the bark or remove whatever is possible through chip washing (thus removing both dirt and bark).

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (18), Hooper (19) and Biltonen, *et al*. (20). Previously cited papers by Besley (3) and Smith and Kozak (8) contain information on moisture content of lodgepole pine and a paper by Cole (21) discusses phloem thickness of lodgepole pine. The potential of bark as fuel is briefly discussed in a paper by Grantham and Ellis (22).

BARK AND WOOD PROPERTIES OF PONDEROSA PINE
(*Pinus ponderosa* Laws.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Ponderosa pine, the most widely distributed pine in North America, ranges from British Columbia in the north to Mexico in the south, and from the Pacific Coast, east to Nebraska. Vast commercial stands are found in British Columbia, Mexico and 11 western states. In this extensive range, it grows in 20 forest types, on a large variety of soils, and at elevations from sea level to 9000 ft. Best development generally occurs on medium-textured soils, well-drained, deep-sandy gravel, and clay loams at elevations of 4,000 to 8,000 ft on benches, plateaus, and west and south aspects. Mature trees attain heights of over 200 ft and diameters in excess of 90 in. dbh.

WOOD AND BARK MORPHOLOGY

Wood

Ponderosa pine wood, frequently dimpled on the tangential surface, is moderately light and soft, medium coarse-textured and usually straight grained. The sapwood, generally 2 inches or more in width, is nearly white to pale yellow. The heartwood ranges from yellowish to light orange-brown. Growth rings are distinct with an abrupt transition from earlywood to darker latewood.

The xylem consists of fiber tracheids, rays, and transverse and longitudinal resin canals. Tracheids average 35-45 μm in diameter and 3.53 mm in length. Rays, accounting for 6.7% of the total wood volume, are of two types. Uniseriate rays are numerous, 1-12+ cells in height. Fusiform rays, often associated with a transverse resin canal, are scattered, 3-5 seriate through the thickened portion, and up to 16+ cells in height. Prominently dentate ray tracheids are present in both types of rays. Ray parenchyma are thin-walled. Resin canals, lined with thin-walled epithelium, are frequently occluded with tylosoids in the heartwood. Longitudinal canals average 160-186 μm in diameter with a maximum of 230 μm. The smaller and less numerous transverse canals are less than 70 μm in diameter.

Bark

Bark of the young ponderosa pine is furrowed and black, but as the tree grows older, becomes yellowish-brown to cinnamon colored and heavily plated. Scales are large and the main portion of the rhytidome lines are parallel to one another. On cross section, the yellowish periderm is in sharp contrast to the reddish brown secondary phloem. In the trees used in this study, the outer bark accounted for 80-95% of the total bark thickness by weight. Figure 9 illustrates a cross section of ponderosa pine wood and bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

The rhytidome of mature bark consists of alternating layers of old periderm and dead phloem. The periderms are rather broad and composed of a layer of phellogen, several layers of expanded parenchymatous cells or phelloderm and a number of thin-walled phellem cells that usually alternate with thick-walled cells. Remnants of the phloem lie to the outside of each periderm and the expanded parenchyma cells or phelloderm occupy much of the area between the periderms.

The secondary phloem is composed of sieve cells, phloem parenchyma and phloem rays. Sieve cells are aligned in radial rows, often four to six cells, sometimes up to ten cells in a continuous row, interrupted by more or less single tangential lines or sometimes sporadically arranged parenchyma cells. These two types of cells are bordered radially by uniseriate and fusiform rays.

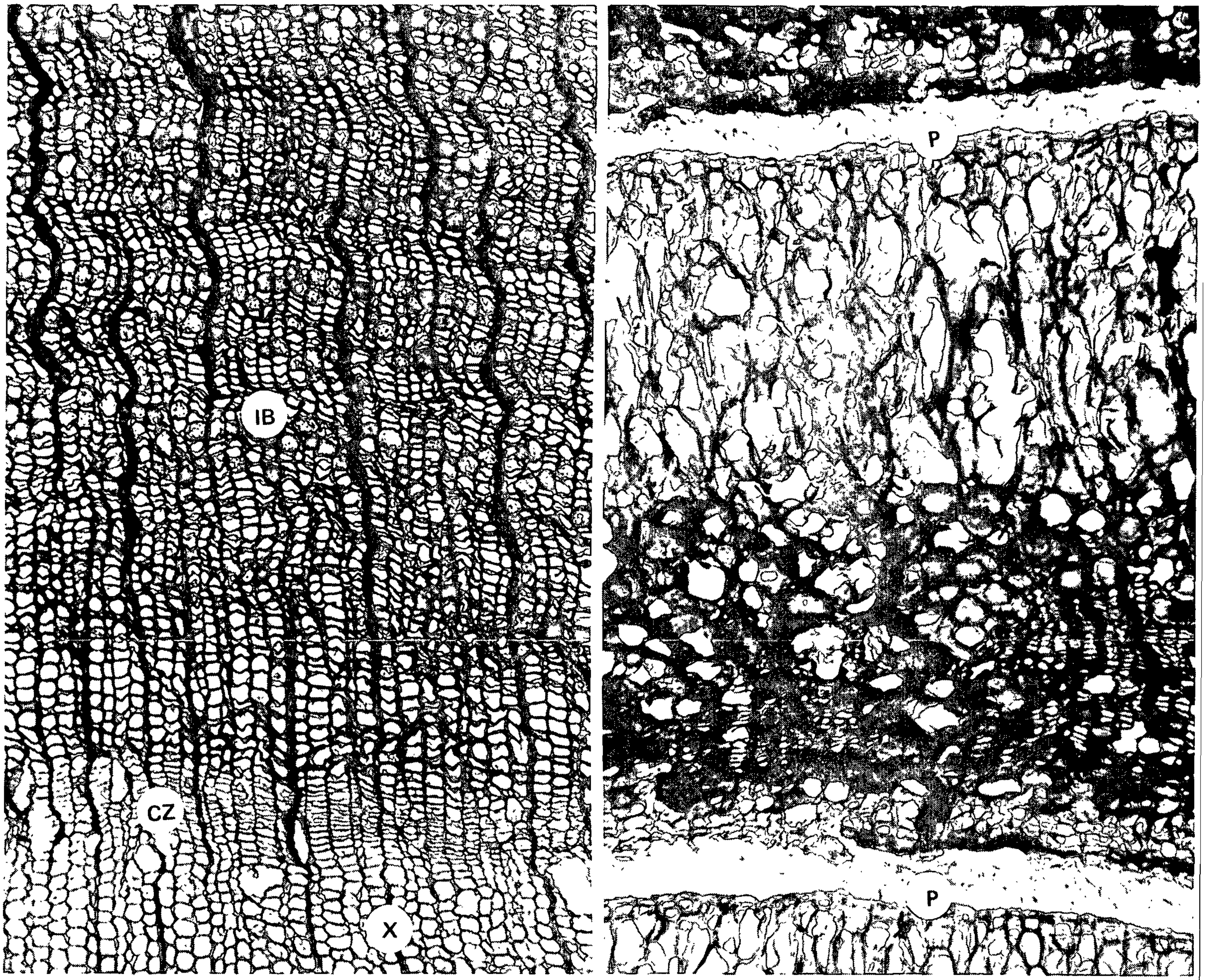


Figure 9. Cross Section of Ponderosa Pine. Photomicrograph on Left Shows Cross Section of Xylem (X), Cambium Zone (CZ) and Inner Bark (IB). Photomicrograph on Right is a Cross Section of the Outer Bark Showing Periderm (P) Layers. The Rhytidome Contains Layers of Secondary Phloem. Magnification — 75X

The sieve cells near the cambium zone average 35-40 µm tangentially and 25-30 µm radially. The average sieve cell length of 2.0 mm obtained for the "On 60 fraction" of bark pulp (see Fibrous Yield section) is considered to be low. The actual average length of whole, unmacerated sieve cells in the bark is probably between 3.0 and 4.0 mm.

The cross sections of the phloem parenchyma cells in the proximity of the cambium zone are similar to the cross sectional area of the sieve cells in this region. The parenchyma cells become expanded and are oval to circular in cross sectional area after a few seasons of growth. The average diameter of these cells is between 40-50 µm. The average longitudinal length of individual parenchyma cells is between 75-100 µm. Most of the parenchyma cells observed during investigation of ponderosa pine bark were completely filled with starch granules (average diameter 10 µm).

The phloem rays attain a height of 8-10 cells (300 µm). Horizontal resin canals are present in the fusiform rays. There is no sclerenchyma present in the bark of ponderosa pine.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

Specific Gravity

Table VII summarizes the information available on wood and bark of ponderosa pine. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of ponderosa pine at several moisture contents.

It was necessary to make a differentiation between sapwood and heartwood and interior and exterior wood for the two trees examined because 3212-72 was a relatively fast-growing tree with very little heartwood. Thus, the first nine rings were called interior wood. Tree 3212-79, on the other hand, was a slow-growing tree with enough heartwood for the characterization tests. An average specific gravity (ovendry weight/green volume) of approximately 0.39 appears appropriate for the wood of ponderosa pine. Our limited data show both the interior and exterior wood of 3212-72 and the heartwood and sapwood of 3212-79 to be similar in specific gravity.

The specific gravity of the total (inner + outer) bark of ponderosa pine is similar in specific gravity to that of the wood. The inner bark of 3212-72 was higher in specific gravity than the outer bark while the reverse was true for 3212-79. Although the barks are visually similar, the two trees are again from different geographic locations (Idaho and Oregon). Overall values suggested for use in species comparisons are 0.39 for wood and 0.34, 0.35, and 0.35 for inner, outer, and total bark.

TABLE VII

PONDEROSA PINE SPECIFIC GRAVITY INFORMATION
(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
0.38						Isenberg (7)
0.38						Besley (U.S.) (3)
0.44						Besley (Canada) (3)
0.37	0.27-0.54					Maeglin & Wahlgren (4)
0.38						Wood Handbook (15)
0.38						IUFRO (6)
				0.39		Voorhies, *et al.* (23)
		0.36	0.34			Smith & Kozak (8)
0.37 (exterior) 0.36 (interior)		0.39	0.36	0.37		IPC 3212-72
0.45 (heartwood) 0.40 (sapwood)		0.28	0.35	0.33		IPC 3212-79
0.42[a]						Isenberg (7)
				0.38[a]		Harkin & Rowe (9)
				0.36[a]		Harkin & Rowe (9)

[a]Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range in levels of extractives from 4.4 to 7.2% has been reported for the wood of ponderosa pine (see Table VIII). For between-species comparisons, an extractives level of 5.3% is suggested for the wood of ponderosa pine. Based upon information obtained from the two trees sampled as part of this project, the bark of ponderosa pine can be expected to have an extractives level of 15.7%. This relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques. Extractives in pines are one of the causes of color reversion in mechanical pulps and can cause problems when the sulfite process is used (10).

TABLE VIII

PONDEROSA PINE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.4	Isenberg (7)
Sapwood	5.1	Anderson (24)
Heartwood	7.2	Anderson (24)
Bark	19.8	IPC 3212-72
Bark	11.6	IPC 3212-79

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of ponderosa pine having an effect on the pulp are sieve cells. There are no true fibers in the bark of ponderosa pine.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could conceivably contribute to felt plugging and drainage problems if built up in sufficient quantitites through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

There is also a minor amount of thick-walled cogwheel-shaped phellem cells in ponderosa pine similar to those found in the southern pines but fewer in numbers. Most of these cells, however, would be lost in the washing and cleaning operations. Under typical kraft pulping (48-52% yield), phellem cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high-yield pulping, some of these phellem cells could remain in clumps and cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, spruce).

As a check on pulp yield and the nature of the material produced from ponderosa pine, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table IX summarizes the results of this investigation.

TABLE IX

PONDEROSA PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-72	Sample No. 3212-79	Remarks
Yield, % solids	27.9	30.3	
Fraction			
On 60 mesh, %	25.4	56.8	The furnish of the fraction contained principally sieve cells (90-95%) with small percentages of thick-walled cog-wheel-shaped phellem cells (5-10%), and peridermal and parenchymatous cells (<5%). The average arithmetic length of the sieve cells contained in the fraction was 2.08 mm (range 0.5-4.7 mm)
On 100 mesh, %	4.4	1.4	The fraction contained a large percentage of sieve cells (80-90%) with small percentages of thick-walled cogwheel-shaped phellem cells (5-10%), peridermal and parenchymatous cells (5-10%)
On 150 mesh, %	9.8	4.2	The fraction contained sieve cells (40-50%), thick-walled cogwheel-shaped phellem cells (30-40%) and peridermal and parenchymatous cells (20-30%)
On 200 mesh, %	7.6	4.2	The fraction contained a large percentage of thick-walled cogwheel-shaped phellem cells (50-60%) with smaller percentages of parenchyma and thin-walled peridermal cells (20-30%) and sieve cells (10-20%)
Through 200 mesh, %	52.8	35.2	The fraction contained a large percentage of thick-walled cogwheel-shaped phellem cells (70-80%) with smaller percentages of thin-walled peridermal and parenchyma cells (20-30%) and sieve cells (<5%)

[a]Percentages given are on a dry weight basis.

Micropulping of ponderosa pine bark resulted in a yield of 27 to 30% solids. When screened, the coarse screens (60 and 100 mesh) retained mostly sieve cells and a minor amount of phellem cells. The on 150-mesh screen also contained a large amount of sieve cells with lesser amounts of phellem, peridermal and parenchymatous cells. The on 200-mesh and through 200-mesh screens contained principally phellem and smaller percentages of parenchyma and peridermal cells. Figure 10 illustrates the type of material on the 60- and 150-mesh screens. The percentages of solids retained on each screen differed greatly between the two trees pulped. After investigating the reason for this, it was determined that the two pulps were not handled identically during fiberizing and classification. Using an average of the two percentages given for each mesh would probably give a fairly accurate idea of what the results should be.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, an average of 29 grams of solids will result. Of this 29 grams, about 12 grams (12%) of sieve cells and 1 gram (1%) of phellem cells will be produced. This assumes that only the material on the 60 and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

As reported previously, papers by Auchter (13) and Horn and Auchter (14) investigated the feasibility of pulping chips containing approximately 10% bark of a number of western species including ponderosa pine. They found that 0.2% more active cooking chemical as caustic soda and 0.2% more chlorine to bleach was needed for chips containing bark. Dirt levels could be lowered to an acceptable level by more efficient use of a centricleaner system and presence of bark in the pulp did not affect strength properties. Although digester yield

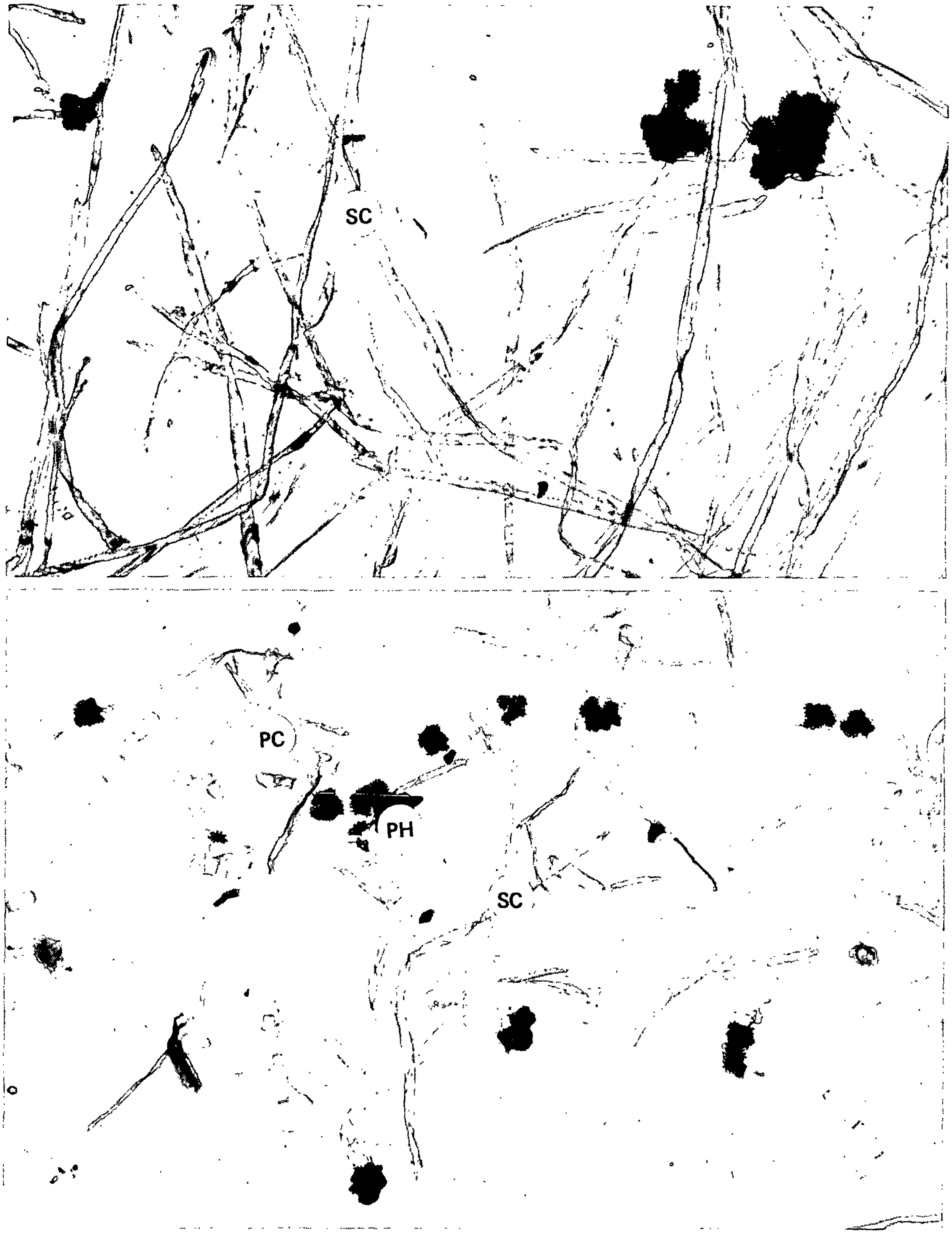


Figure 10. The 60-Mesh Screen (Top) Contained by Weight Principally Sieve Cells (90-95%). The 150-Mesh Screen (Bottom) Contained Sieve Cells (40-50%), Phellem Cells (30-40%) and Peridermal and Parenchymatous Cells (20-30%). Magnification — 75X. Symbols Illustrate Sieve Cells (SC), Phellem Cells (PH) and Parenchymatous and Peridermal Cells (PC)

from rough wood was less, the net gain per rough cord would be at least 4% higher for unbarked chips. They also felt that another 5-10% gain in yield could be realized because there would not be the wood loss usually incurred during barking. In our opinion, the net gain of 4% per rough cord would consist mainly of less useful sieve cells.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for ponderosa pine samples collected July 8 (growing season), October 12 and December 8. Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 11 illustrates the zones of failure for ponderosa pine. During the growing season, wood/bark adhesion was moderately low (5.0 kg/cm^2) and the failure zone occurred between immature xylary initials in the proximity of the cambium zone. Secondary wall thickening was still in process. It appeared, after examination of the October 12 Instron-tested sample, that the tree (from Idaho) was still not fully dormant. Adhesion values averaged 4.2 kg/cm^2, about the same as the growing season values. Microscopic examination indicated the failure zone to be primarily between cells in the cambium zone located 1-2 cells

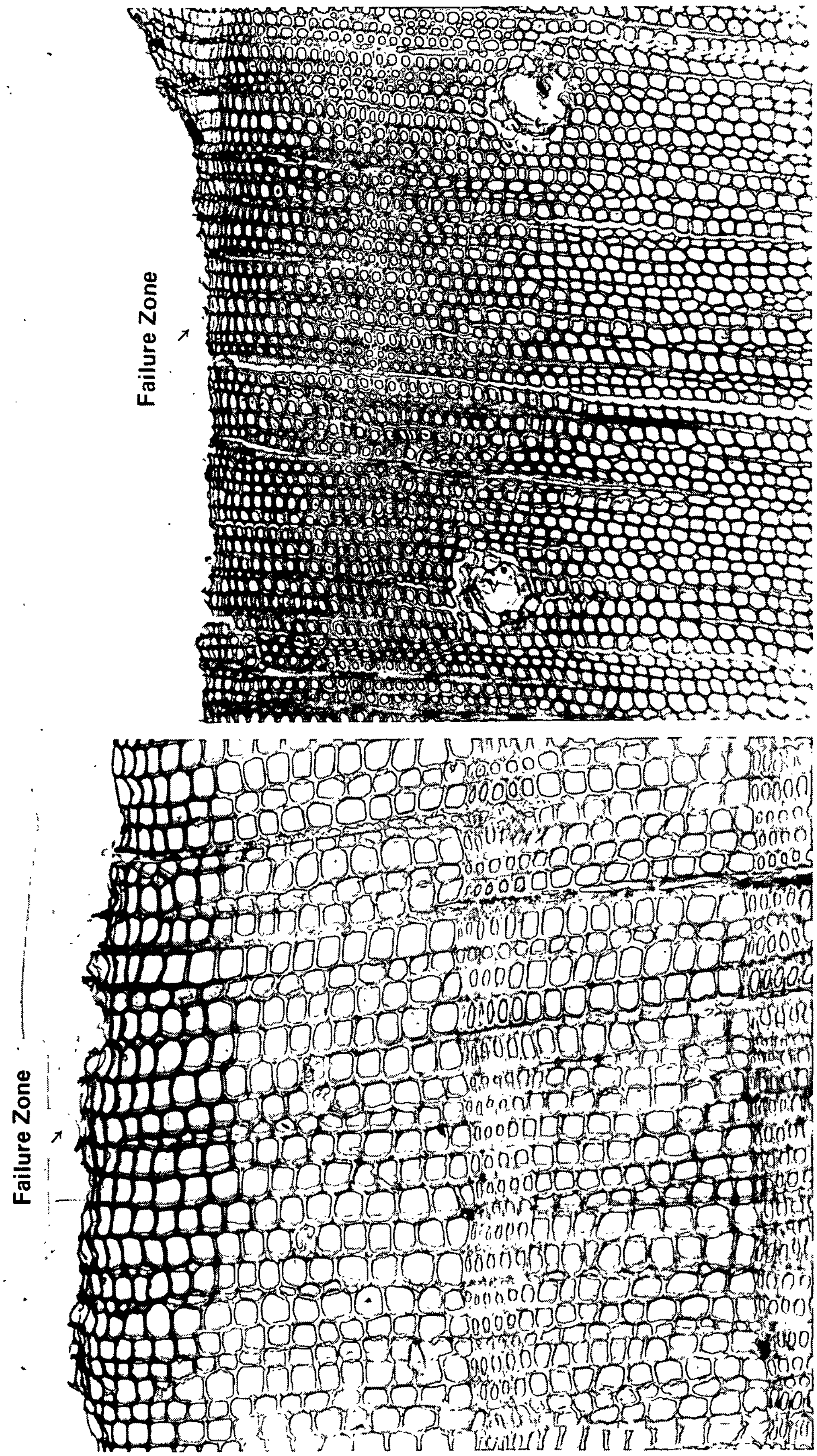


Figure 11. Illustrated are Zones of Failure for Ponderosa Pine. Failure During the Growing Season (Left) Occurred Between Immature Xylem Cells in the Proximity of the Cambium Zone. On the Right is a Sample Collected October 12. The Sample was not Entirely Dormant and Failure Occurred Between Cells in the Cambium Zone 1-2 Cells from Mature Latewood Xylem Tracheids. One Small Corner of the Break Extended Approximately 0.5 mm into the Phloem. Magnification — 125X Left, 75X Right

from the mature latewood xylem tracheids. One small corner of the break (tangential measurement approximately 1.0 mm) extended approximately 0.5 mm into the phloem. The cell walls of the cambial initials were probably not as thick as they would eventually become later in the dormant season. Another sample of ponderosa pine from Idaho was collected December 8 and adhesion values averaged 9.6 kg/cm^2. Although this sample was not examined morphologically because of resampling time limitations it seems safe to assume that the sample was dormant because of the increased adhesion value. The failure zone was probably located in the secondary phloem based upon experience with other softwood dormant season samples and the indication that the failure zone was beginning to move into the secondary phloem in the October 12 sample.

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids or phellem cells and a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of ponderosa pine.

Bark strength values for ponderosa pine were moderate compared to other softwoods tested thus far. Outer bark strength was only slightly higher than inner bark strength. The toughness values for wood were relatively low although considerably greater than the bark values. The low toughness values obtained for wood make it appear that hammermilling or a similar technique might not work well on this species. The low toughness and moderate strength values for the bark are probably related to the lack of fiber and high percentage of sieve cells in ponderosa pine.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF PONDEROSA PINE[a]

Material	Strength	Toughness
Wood	--	0.26
Inner bark	4.6	0.10
Outer bark	4.9	0.08

[a]Determinations average of two different trees.

Toughness tests on a number of species, as reported by Wood Handbook (15), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test was done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. At 11% moisture content, Wood Handbook results show ponderosa pine wood with a tangential value of 190. In comparison, at 11-12% moisture content, values for loblolly pine were 260, slash pine — 320 and jack pine — 240. Lodgepole pine had a value of 210 in a green condition. Our results also indicate that ponderosa pine wood is not as tough as the wood of any of these other species. When enough data are obained, correlations will be run between IPC toughness values, Wood Handbook toughness values and hammermilling results.

Summarized in Table XI are the results of the hammermilling tests run on ponderosa pine wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON PONDEROSA PINE

Tree No.	Material	Fraction Retained on Standard Screen, %[a] 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-72	Bark	17	43	15	8	7	10	Inner bark thin and seems to stay attached to outer bark
	Sapwood	85	9	3	1	1	1	
	Heartwood	75	16	4	2	1	2	
3212-79	Bark	12	39	20	9	7	12	Inner bark thin and seems to stay attached to outer bark
	Exterior	76	16	4	2	1	2	
	Interior	62	29	5	2	1	1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and a 26% reduction in bark. This is a fairly low bark removal compared to other softwoods investigated thus far, confirming results obtained from the toughness tests. A much larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss is also doubled (44% bark removal and 8% wood loss). This additional 4% loss in wood might be acceptable in view of the increased amount of bark removed and the fuel value of the wood. Voorhies, et al., in hammermilling ponderosa pine bark, also found the largest amount of bark was retained on a screen with openings of 2.0 mm (about 30%). Figure 12 illustrates the effect of hammermilling on wood and bark of ponderosa pine. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 12 (16, 17). Summary Table XXVII compares bark strength, toughness and reaction to hammermilling of ponderosa pine to other species tested ths far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

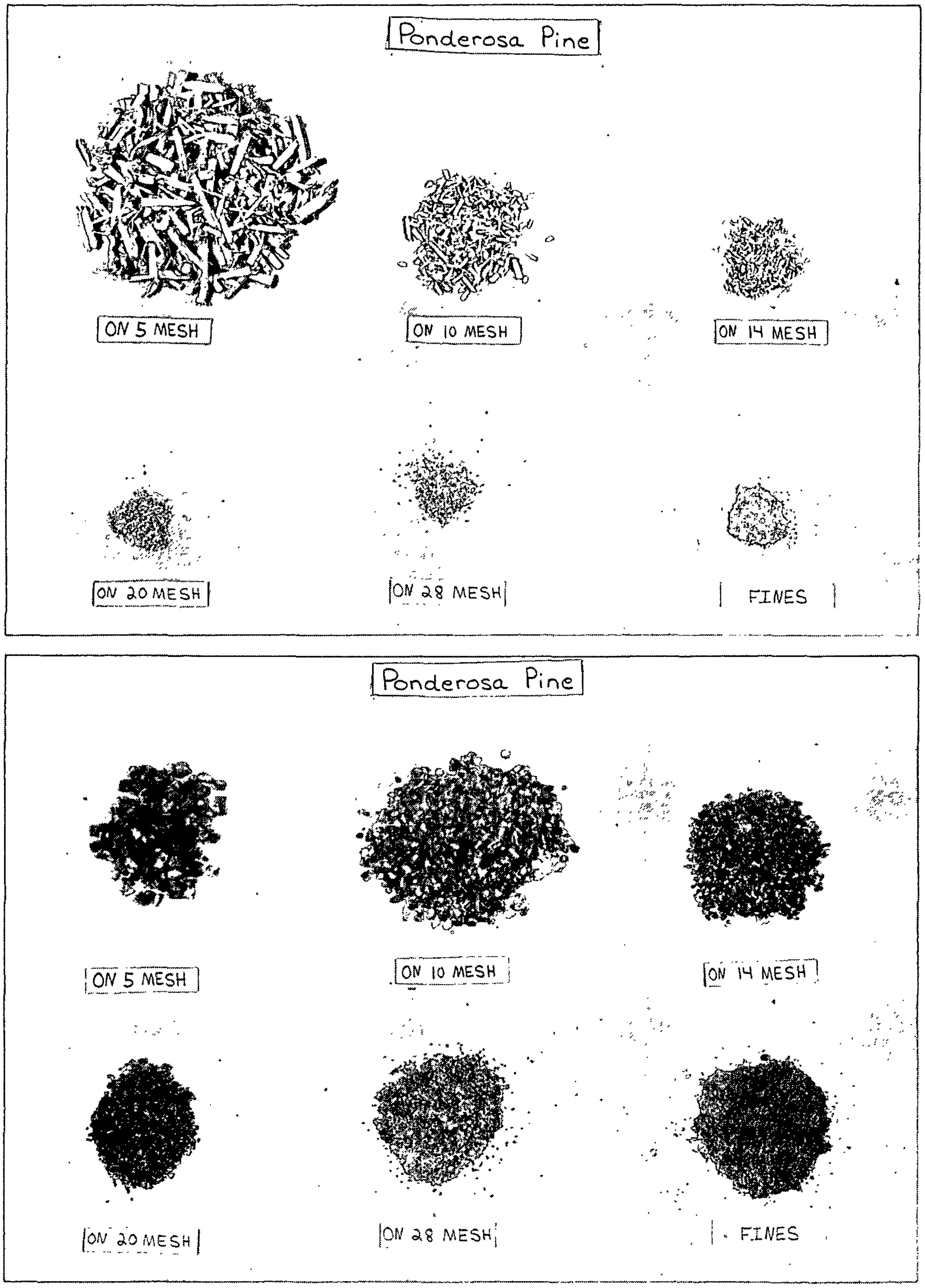


Figure 12. Illustrated is the Effect of Hammermilling on Ponderosa Pine Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two ponderosa pine trees (IPC 3212-72 and IPC 3212-79) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for both trees had a somewhat higher density than whole bark while the outer bark had approximately the same density as whole bark. It appears that outer bark, which makes up a much larger proportion of the bark than does the inner bark, would behave similarly to total bark under flotation conditions.

Figure 13 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

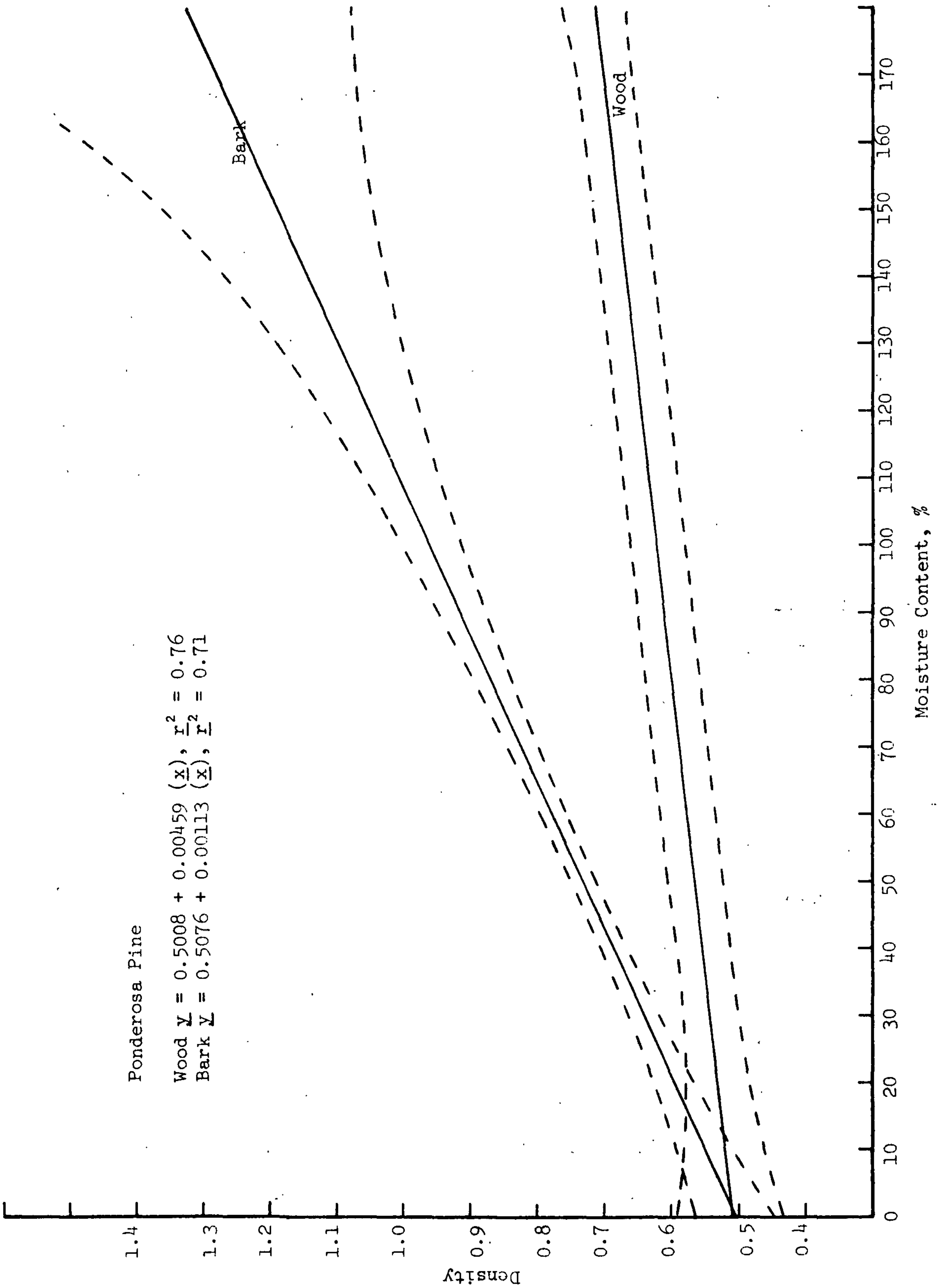


Figure 13. Illustrated is the Relationship Between Basic Density and Moisture Content for Ponderosa Pine. The Dashed Lines are Two Standard Deviations Above and Below the Mean

regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that, at moisture contents of 120% or greater, most wood chips could be expected to sink (density greater than 1). Ponderosa pine bark, on the other hand, could be expected to float even at very high moisture contents (density less than 1). From the curve it appears that ponderosa pine bark takes up moisture very slowly.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XII summarizes the results for ponderosa pine. These results agree with the results

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR PONDEROSA PINE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-72	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-72	After 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-72	After 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-79	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-79	After 5	0	100
Exterior	15	0	100
	60	0	100
	240	0	100
IPC 3212-79	After 5	0	100
Interior	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. It was noticed, however, that after 4 hours a small amount of unattached inner bark had sunk, further confirming density determinations which showed inner bark to have a higher density than either whole bark or outer bark. It is probable that inner bark also takes up moisture more readily.

DATA INTERPRETATION

Ponderosa pine behaved in a similar fashion to lodgepole pine in IPC tests and the comments that applied to lodgepole pine would also apply to ponderosa pine. Ponderosa pine bark contains no fiber and analysis showed 12% sieve cells and 1% phellem cells retained in the pulp. Again, the sieve cells would act as filler in the paper but probably would not contribute to paper properties. The phellem cells could cause problems in high-yield pulping by remaining in clumps and causing "fisheyes."

Extractives in ponderosa pine bark are fairly high and this, plus the lack of fiber, make removal of at least part of the bark desirable. Like lodgepole pine, dormant season adhesion values are low and reasonable separation of wood and bark through action of the chipper might be achieved. The species did not react well to hammermilling with only a 26% reduction in bark when the material on the 14-mesh screen was retained. By only retaining the material on the 10-mesh screen, the result was a 44% bark removal but an 8% wood loss. However, this method might be a way of quickly upgrading chips. Involved would be screening, hammermilling the fractions high in bark and rescreening. It appears that lodgepole pine and ponderosa pine could be handled together in a species mixture. Segregation of ponderosa pine wood and bark through water flotation is possible but the high moisture contents required (120% or more) do not make the method feasible. The wet rejects would also be less valuable as fuel.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (18), Hooper (19), and Biltonen, *et al*. (20). Previously cited papers by Besley (3) and Smith and Kozak (8) contain information on moisture content of ponderosa pine and the previously cited paper by Harkin and Rowe (9) gives pounds of bark per cubic foot of wood by diameter classes. The potential of bark as fuel is briefly discussed in a paper by Grantham and Ellis (22).

BARK AND WOOD PROPERTIES OF ENGELMANN SPRUCE
(*Picea engelmannii* Parry)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Engelmann spruce, a major component of the high-elevation forests of the Rocky Mountain region, is found in extensive stands in nine western states and two Canadian provinces. Its range extends from British Columbia and Alberta, south to New Mexico and Arizona. Not normally grown in pure stands, spruce predominates in the mixed composition forests throughout the Rocky Mountains. It is a minor component of the high-level forests on the east slopes of the Pacific coastal ranges from British Columbia to Mount Shasta in northern California. In a climatic zone classified as cold and humid, the general range of Engelmann spruce occupies the highest and coldest forest environment in the western United States. Best growth occurs on moderately deep, well-drained silt and clay loam soils, developed from basalt, andesite, rhyolite, shale, and limestone. It does not grow well on shallow, dry, coarse-textured sands and gravels, heavy clay-surfaced soils or saturated soils. Elevations may range from 2,500 ft on the coastal ranges in British Columbia to 11,000 ft in the central Rocky Mountains. A long-lived tree and one of the largest of the high mountain species with maturity occurring in about 300 years, a mature Engelmann spruce will average 18-36 inches in diameter and 100-120 ft in height in good environment.

WOOD AND BARK MORPHOLOGY

Wood

The wood of Engelmann spruce is nearly white to pale yellowish-brown with an indistinct heartwood. It is usually straight-grained, fine textured, and light to moderately light. Growth rings are distinct, delineated by a usually wide earlywood zone with a gradual transition to a generally narrow, darker latewood.

Resin ducts, visible as white specks in the latewood, are few in number but distinguish the wood of Engelmann spruce from white fir and other western true firs. The longitudinal tracheids average 25-30 μm in diameter and about 2.96 mm in length. Longitudinal parenchyma are lacking. Rays are of two types with non-dentate ray tracheids present in both. Uniseriate rays, 1-16+ cells in height, are numerous. Biseriate rays are rare. Fusiform rays, scattered with one or rarely two resin canals, are 2-3 seriate through the central thickened portion tapering to uniseriate and about the same height. The transverse resin canals have diameters of usually less than 30 μm and the longitudinal canals average 50-90 μm. The ducts, lined with 7-9 thick-walled epithelial cells, have occasional tylosoids in the heartwood.

Bark

The bark of Engelmann spruce is very thin and rough with dull, reddish-brown loosely attached scales. The total thickness of the bark on mature trees is about 0.3 inch. The inner bark, comparatively light in color, is about 0.18 inch thick. In the trees used in this study, the outer bark accounted for 60-80% of the total bark thickness by weight. Figure 14 illustrates a cross section of Engelmann spruce wood and bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

On a young tree or branch the epidermis consists of cutinized epidermal cells, uniseriate multicellular hairs, and at the concave portions, small groups of collenchyma cells formed from the hypodermis beneath. The periderm, with thin-walled and enlarged phellem cells, originates from the outer margin of the cortex. Cortex parenchyma, resin cells, sclereids, and vertical resin canals comprise the rather broad cortex. The secondary phloem has the same basic cell pattern arrangement as in the mature tree.

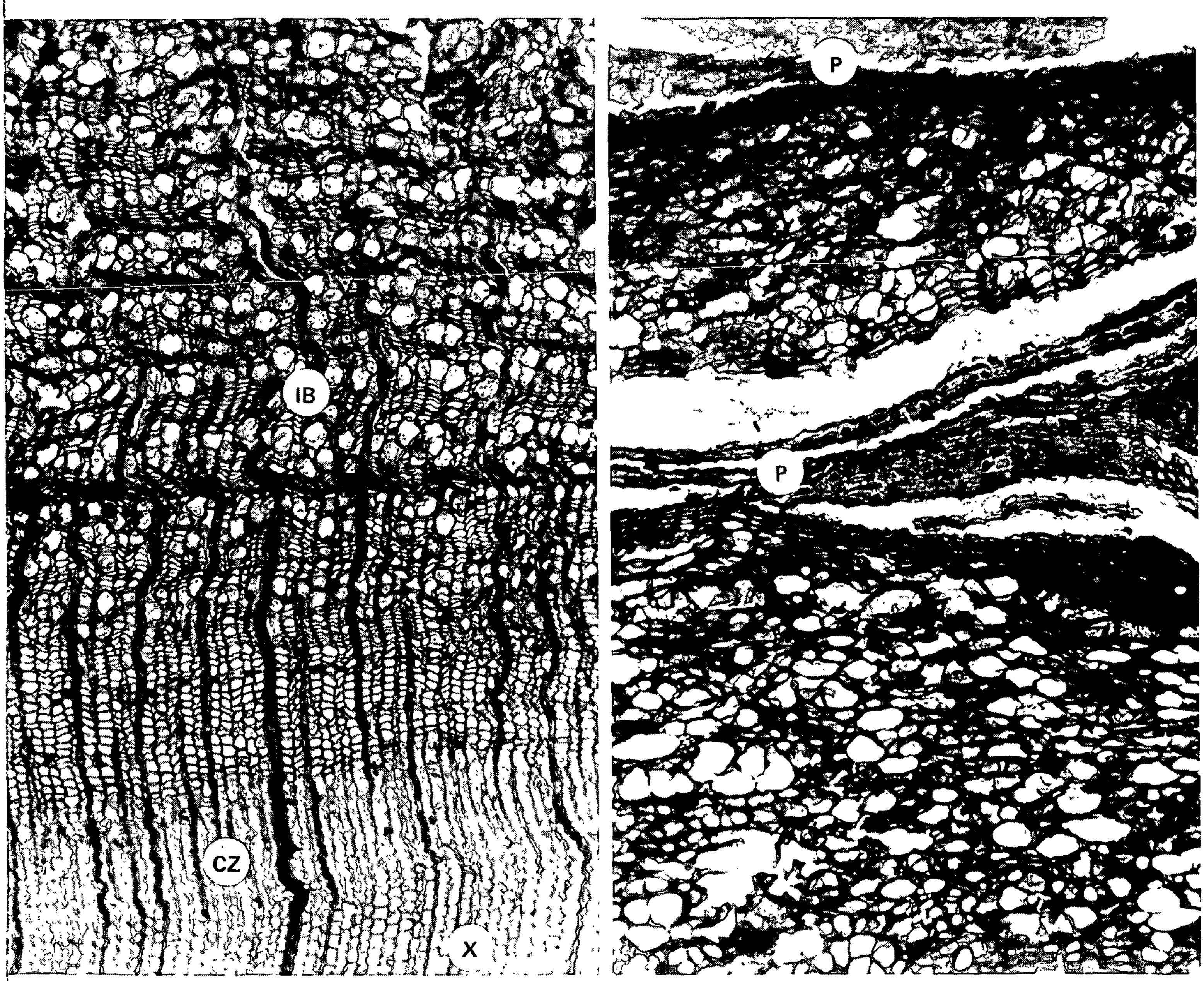


Figure 14. Cross Section of Engelmann Spruce. Photomicrograph on Left Shows the Xylem (X), Active Cambium (CZ) and Inner Bark (IB). Photomicrograph on Right is a Cross Section of the Outer Bark Showing the Periderm (P) Layers. Magnification — 75X

In the mature bark, new periderm develops rather often producing the narrow layers of rhytidome. The periderm is composed of 2-6 layers of phelloderm, a layer of phellogen and usually 2-4 layers of uniform, thin-walled and suberized phellem cells. The cells are regularly aligned and rectangular or nearly square in shape, about 30 μm in diameter on cross section and 40-70 μm high on tangential section. Phelloderm cells are parenchymatous in nature often becoming "lignified" and thick-walled, and at times alternating with the thin-walled phellem cells. Resinous substances and crystals are often found in the periderm cells.

The secondary phloem consists of sieve cells, parenchyma, and uniseriate and fusiform rays. The inner bark of Engelmann spruce, unlike other spruces, seldom develops sclereids. (Small groups of thick-walled, branched and twisted cells are sporadically distributed in the outer bark.) Sieve cells, aligned in radial rows and interrupted by parenchyma about every 5-7 cells, vary in length from 2.10-4.40 mm. Tangentially aligned in more or less continuous rows, newly differentiated parenchyma are about the same size and shape as sieve cells on cross section but expand quickly after a few seasons' growth. Individual cells containing abundant tanniferous substances, starch and crystals, are about 100-150 μm in height. Parenchyma strands are usually about the same length as the adjacent sieve cells. Uniseriate rays are usually 14 cells or about 250 μm high and sometimes up to 400 μm high. Erect marginal cells or albuminous cells are conspicuous in every ray close to the cambial zone. Fusiform rays contain the resin canals with thin-walled epithelial cells lining the ducts. Deformed sieve cells, expanded parenchyma and dilated rays occur in the transformation of the secondary phloem tissues to the rhytidome.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fibr yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIII summarizes the information available on wood and bark of Engelmann spruce. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of Engelmann spruce at several moisture contents.

The specific gravity of the total (inner + outer) bark of Engelmann spruce is somewhat higher than that of the wood. The inner bark of the two trees sampled as part of the project was lower in specific gravity than the outer bark. The same trend was also reported by Smith and Kozak (8). Overall values suggested for use in species comparisons are 0.34 for wood and 0.41, 0.52, and 0.51 for inner, outer, and total bark.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE XIII

ENGELMANN SPRUCE SPECIFIC GRAVITY INFORMATION
(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
0.31						Isenberg (7)
0.35						Maeglin & Wahlgren (4)
0.32						Wood Handbook (15)
0.32						Besley (U.S.) (3)
0.38						Besley (Canada) (3)
0.33						IUFRO (6)
		0.45	0.53			Smith & Kozak (8)
0.33 (sapwood) 0.37 (heartwood)		0.46	0.55	0.55		IPC 3212-75
0.37 (sapwood)		0.31	0.47	0.47		IPC 3212-77
0.35[a]						Isenberg (7)
				0.80[a]		Harkin & Rowe (9)

[a]Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Extractives levels of 2.8% have been reported for the wood of Engelmann spruce (see Table XIV). Based upon information obtained from the literature and from the two trees sampled as part of this project, the bark of Engelmann spruce can be expected to have an extractives level of 24.4%. This high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques.

TABLE XIV

ENGELMANN SPRUCE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.8	Fengel & Grosser (11)
Wood	2.8	Rydholm (12)
Wood	2.8	Isenberg (7)
Bark	31.1	Harkin & Rowe (9)
Bark	19.0	IPC 3212-75
Bark	23.0	IPC 3212-77

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of Engelmann spruce having an effect on the pulp are sieve cells and sclereids. Chang (1) estimated that 77.8% of the tissue elements in the inner bark are sieve cells. He also reported 0.5% sclereids but said that in most specimens, there are no sclereids shown in the inner bark. There are no true fibers in the bark of Engelmann spruce.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Estimates made of IPC macerated bark samples suggest that sclereids make up 2-4% of the total bark weight.

As a check on pulp yield and the nature of the material produced from Engelmann spruce, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XV summarizes the results of this investigation. Micropulping Engelmann spruce bark resulted in a yield of 21-28% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells

TABLE XV

ENGELMANN SPRUCE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-75	Sample No. 3212-77	Remarks
Yield, % solids	27.5	21.4	
Fraction			
On 60 mesh, %	24.6	60.6	The fraction contained a large percentage of sieve cells (70-80%) with a smaller percentage of branched thick-walled sclereids (20-30%). The average arithmetic length of the sieve cells contained in the fraction was 1.97 mm (range 0.5-3.5 mm)
On 100 mesh, %	4.6	3.4	The fraction contained sieve cells (60-70%), sclereids (20-30%), thick-walled peridermal cells (5-10%) and thin-walled parenchyma and peridermal cells (<5%)
On 150 mesh, %	6.2	5.4	The fraction contained thin-walled parenchyma and peridermal cells (40-50%), sieve cells (20-30%), sclereids (10-20%) and thick-walled peridermal cells (<5%)
On 200 mesh, %	5.4	3.4	The fraction contained a large percentage of thin-walled parenchyma and peridermal cells (60-70%) with smaller percentages of sclereids (10-20%), thick-walled peridermal cells (5-10%), and sieve cells (<5%)
Through 200 mesh, %	59.2	27.2	The fraction contained a large percentage of thin-walled parenchyma and peridermal cells (70-80%), thick-walled peridermal cells (20-30%) and a trace of sieve cells (<1%)

[a]Percentages given are on a dry weight basis.

and over half of the sclereids. The on 150-mesh screen contained mainly thin-walled parenchyma and peridermal cells with some sieve cells and sclereids. The on 200-mesh and through 200-mesh screens contained principally thin-walled parenchyma and peridermal cells with some sieve cells and sclereids. Figure 15 illustrates the type of material on the 60- and 150-mesh screens. The percentages of solids retained on each screen differed greatly between the two trees pulped. After investigation, it was determined that the two pulps were not handled identically during fiberizing and classification. Using an average of the two percentages given for each mesh would probably give a fairly accurate idea of what the results should be.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 24 grams of solids will result. Of this 24 grams, about 8 grams (8%) of sieve cells and 3 grams (3%) of sclereids will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

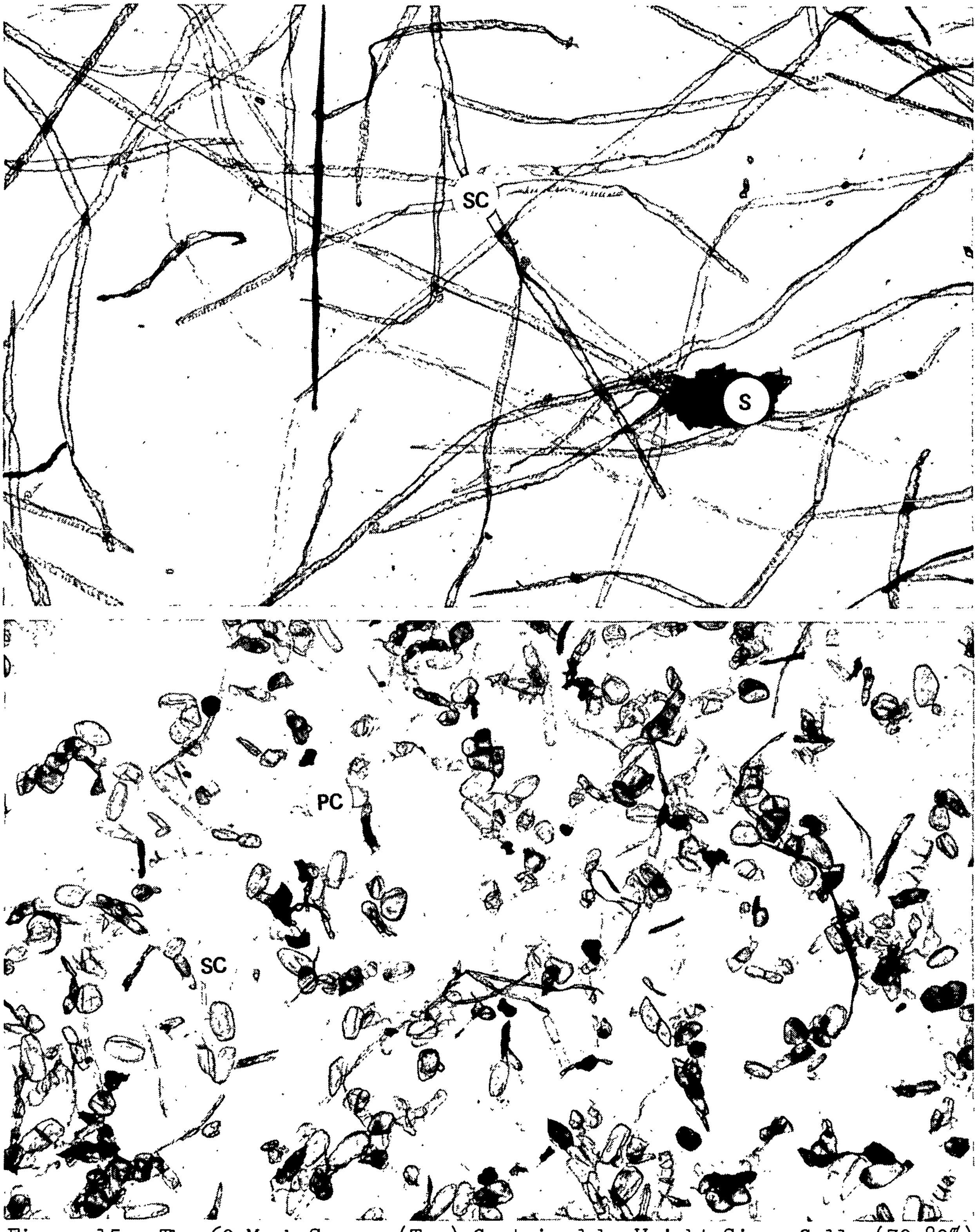


Figure 15. The 60-Mesh Screen (Top) Contained by Weight Sieve Cells (70-80%) and Sclereids (20-30%). The 150-Mesh Screen (Bottom) Contained Parenchyma and Peridermal Cells (40-50%), Sieve Cells (20-30%) and Sclereids (10-20%). Magnification — 75X. Symbols Illustrate Sieve Cells (SC), Parenchyma and Peridermal Cells (PC) and Sclereids (S)

Wood/bark adhesion values were measured for Engelmann spruce samples collected July 25 (growing season), October 12 and December 8. Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figures 16 and 17 illustrate the zones of failure for Engelmann spruce. During the growing season, wood/bark adhesion was low ($3.4\ kg/cm^2$) and the failure zone was located between the immature xylary initials in the proximity of the cambium zone. For the October 12 sample (from Idaho), wood/bark adhesion increased to $9.3\ kg/cm^2$ but failure again occurred in the cambium zone 1-2 cells from the mature latewood xylem tracheids. Indications are the sample was not fully dormant much as was the case with ponderosa pine. The cell walls of the cambial initials were probably not as thick as they would eventually become later in the dormant season. Another sample of Engelmann spruce from Idaho was collected December 8 and adhesion values averaged $12.5\ kg/cm^2$. Although this sample was not examined morphologically because of resampling time limitations, it also seems safe to assume that the sample was dormant because of the higher dormant season adhesion value. The failure zone was probably located in the secondary phloem, based upon experience with other softwood dormant season samples.

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

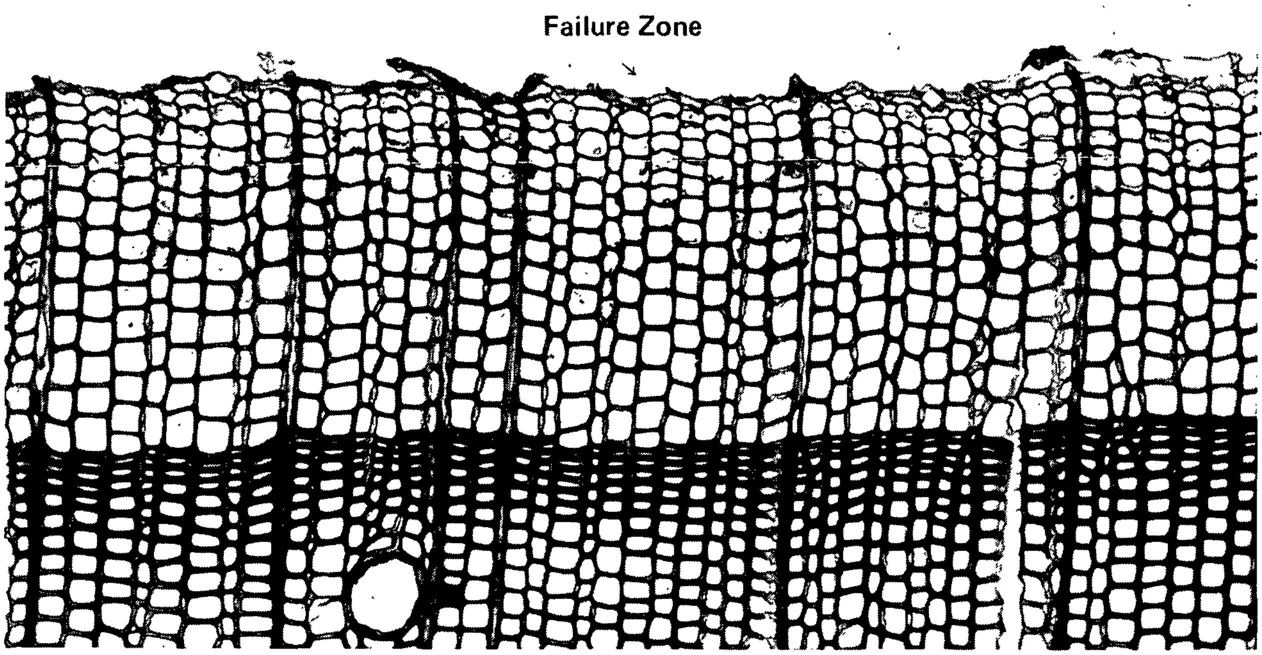


Figure 16. Illustrated is the Engelmann Spruce Growing Season Failure Zone. The Failure Zone Occurred Between Immature Xylem Cells in the Proximity of the Cambium Zone. Magnification — 125X

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

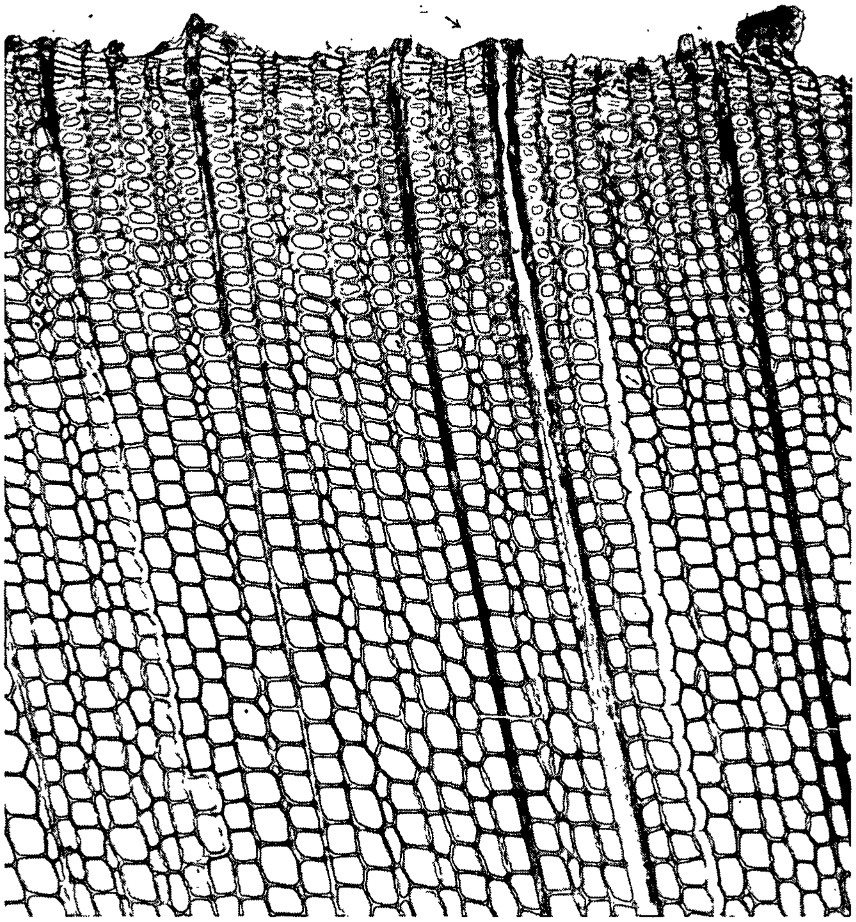


Figure 17. Illustrated is the Zone of Failure for an Engelmann Spruce Sample Collected October 12. The Sample was not Entirely Dormant and Failure Occurred Between Cells in the Cambium Zone 1-2 Cells from Mature Latewood Xylem Tracheids. Magnification — 125X

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of Engelmann spruce.

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF ENGELMANN SPRUCE[a]

Material	Strength	Toughness
Wood	--	0.26
Inner bark	--[b]	0.24
Outer bark	4.2	0.16

[a]Determinations average of two different trees except outer bark toughness which is based on one tree.
[b]Too thin to test.

Only outer bark strength was able to be obtained for Engelmann spruce because of the thinness of the inner bark. Outer bark strength was moderate compared to other softwoods investigated thus far. The toughness values for wood were relatively low and quite similar to the inner bark value. The low toughness values obtained for wood make it appear that hammermilling or a similar technique might not work well on this species. The effectiveness of hammermilling might be further complicated by the relatively high toughness of the inner bark.

Toughness tests on a number of species, as reported by Wood Handbook (15), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test was done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. At 12% moisture content, Wood Handbook results show Engelmann spruce wood with a tangential value of 180. In comparison, at 11-12% moisture content, values for loblolly pine were 260, slash pine — 320, jack pine — 240, lodgepole pine — 210 (green), and ponderosa pine — 190. Our results indicate that Engelmann spruce wood has about the same degree of toughness as ponderosa pine and both have lower values than the other species mentioned. These results agree with results shown in the Wood Handbook toughness table. When enough data are obtained, correlations will be run between IPC values and hammermilling results.

Summarized in Table XVII are the results of the hammermilling tests run on Engelmann spruce wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON ENGLEMANN SPRUCE

		Fraction Retained on Standard Screen, %[a]						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-75	Bark	21	41	15	7	6	12	Inner bark very thin and
	Sapwood	66	28	4	1	1	1	seems to stay attached
	Heartwood	80	15	3	1	1	1	to outer bark
3212-77	Bark	22	37	16	6	5	14	Inner bark very thin and
	Sapwood	53	36	8	2	1	1	seems to stay attached
	Heartwood	45	41	11	2	1	1	to outer bark

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and a 25% reduction in bark. This is a fairly low bark removal compared to many of the other softwoods investigated thus far, confirming the results obtained from the toughness tests. It is interesting that both the IPC and Wood Handbook toughness values for Engelmann spruce and ponderosa pine wood were similar and the hammermilling results were also very similar. A much larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss is also at least doubled (40% bark removal and 10% wood loss). This additional 6% loss in wood might be acceptable in view of the increased amount of bark removed and the fuel value of the wood. Figure 18 illustrates the effect of hammermilling on wood and bark of Engelmann spruce. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 18 (16, 17). Summary Table XXVII compares bark strength, toughness and reaction to hammermilling of Engelmann spruce to other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of

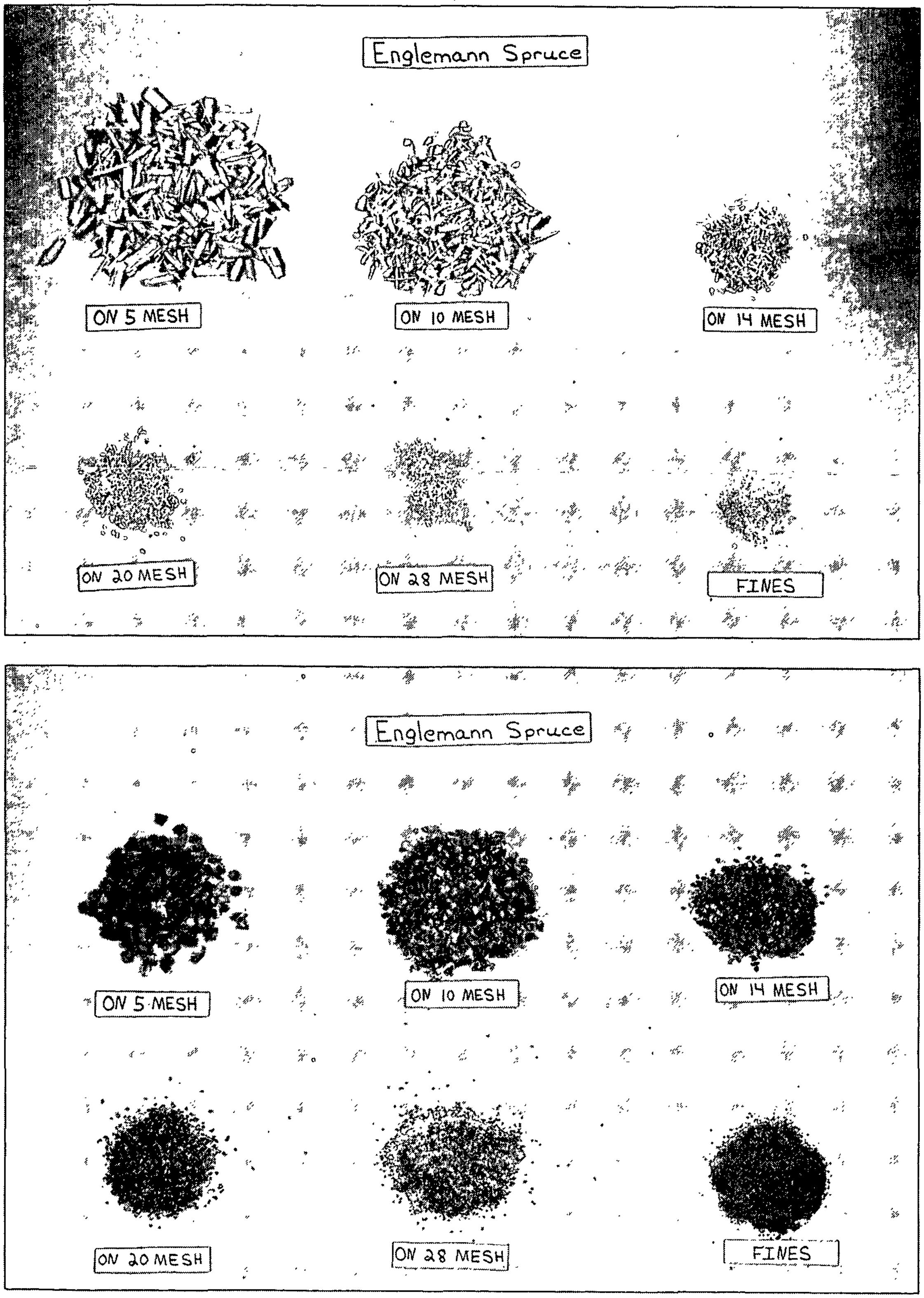


Figure 18. Illustrated is the Effect of Hammermilling on Engelmann Spruce Wood (Top) and Bark (Bottom)

moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two Engelmann spruce trees (IPC 3212-75 and IPC 3212-77) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer, and total bark appeared to have similar densities at the same moisture content.

Figure 19 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

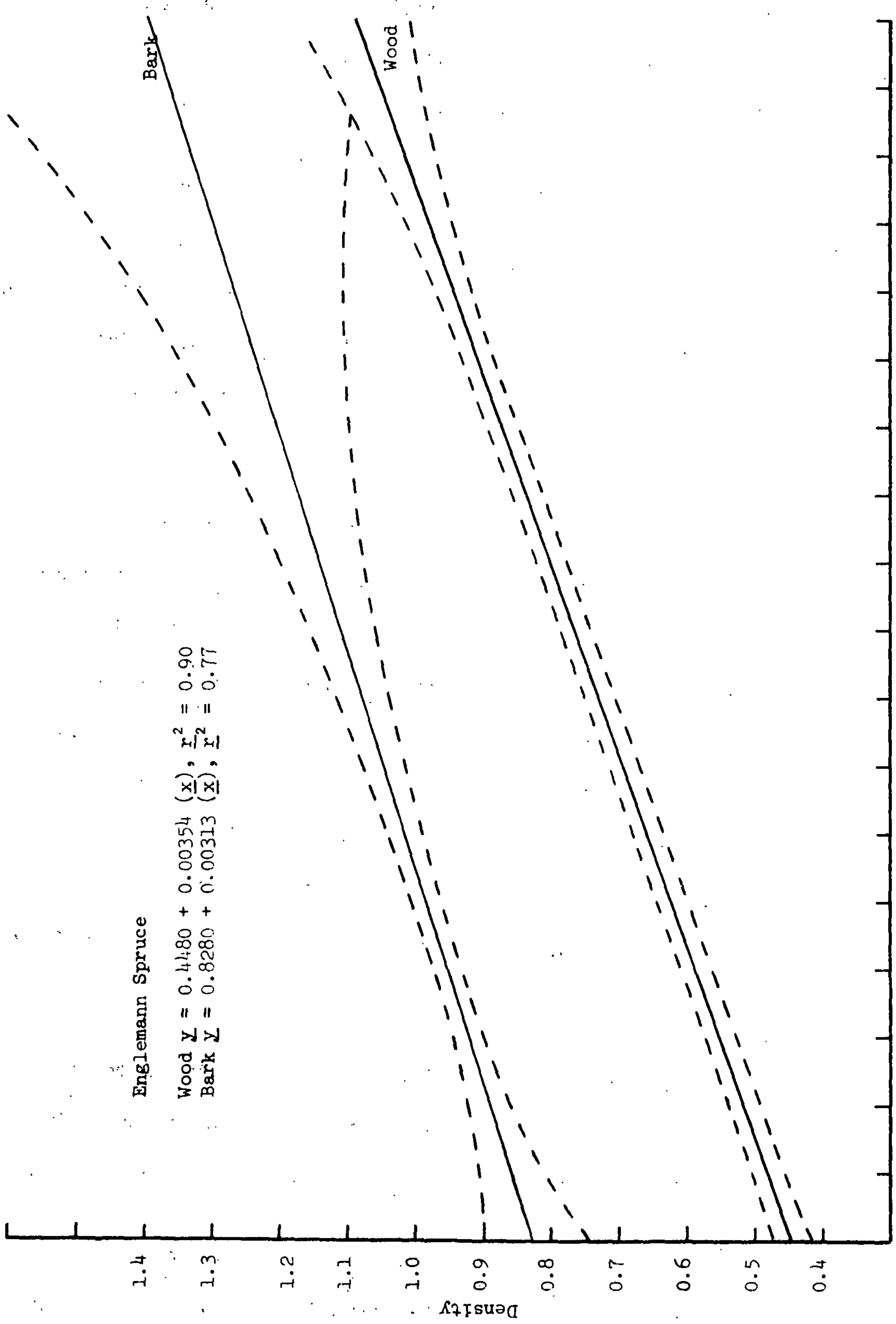


Figure 19. Illustrated is the Relationship Between Basic Density and Moisture Content for Engelmann Spruce. The Dashed Lines are Two Standard Deviations Above and Below the Mean

deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that, at moisture contents of between 60 and 140%, most bark chips could be expected to sink (density greater than 1). Engelmann spruce wood, on the other hand, could be expected to float (density less than 1). This is a fairly wide range of moisture contents available for segregation and makes water flotation a feasible technique for Engelmann spruce.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table

XVIII summarizes the results for Engelmann spruce. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content.

DATA INTERPRETATION

Engelmann spruce bark contains no fiber and a modest amount of sclereids. For every 100 grams of bark that is pulped, about 8 grams of sieve cells and 3 grams of sclereids will be produced. As stated previously, the sieve cells would not contribute to paper properties but would act mainly as filler in the paper. In addition, sclereids could cause problems in high-yield pulping.

Extractives in Engelmann spruce bark are high (24.4%) and this, together with the lack of fiber, makes removal of the bark desirable in many instances. Wood/bark adhesion during the dormant season is moderate and some separation should be accomplished through action of the chipper. The species was among the lowest in amount of bark removed by hammermilling. By retaining the material on a 14-mesh screen, the result was a 25% bark removal. Increasing the screen size to 10-mesh resulted in a 40% bark removal but also a 10% wood loss. Chip screening might be a way of quickly upgrading chip quality. Involved would be screening, hammermilling the fractions high in bark and rescreening. Water flotation also has some promise with this species with segregation appearing possible at moisture contents between 60 and 140%. It is possible that water flotation could be used together with the screening-hammermilling-rescreening technique for effective segregation, although the wet rejects would be less useful as fuel. The bark of Engelmann spruce is thin, suggesting that, because of the low percentage of bark, it may be possible in some instances to either not remove the bark or remove whatever is possible through chip washing (thus removing both dirt and bark).

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR ENGELMANN SPRUCE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-75	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-75	After 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-75	After 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-77	After 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-77	After 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-77	After 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (18), Hooper (19), and Biltonen, *et al.* (20). Previously cited papers by Besley (3) and Smith and Kozak (8) contain information on moisture content of Engelmann spruce. The potential of bark as fuel is briefly discussed in a paper by Grantham and Ellis (22).

BARK AND WOOD PROPERTIES OF WESTERN LARCH
(*Larix occidentalis* Nutt.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Western larch, one of the most important species of the northern Rocky Mountains, occurs only in the Upper Columbia Basin of North America. It grows from southeastern British Columbia through western Montana west of the Continental Divide, northern Idaho and northeastern Washington. It is also found on the east slopes of the Cascades in central Washington and Oregon and the Blue Mountains of eastern Oregon.

Largest of the American larches, western larch grows best in cool climates on deep, porous soils of mountain slopes and valleys that may be gravelly, sandy or loamy in texture. Northerly exposures, valley bottoms and rolling topography are characteristic sites with elevations of 2000-5500 ft in the north and 7000 ft in the southern range, probably limited only by temperatures. One of the few deciduous conifers in North America and long-lived, western larch attains its largest size in western Montana frequently reaching the age of 700+ years. With trunks frequently free of branches for considerable height, trees average about 90 ft at about 120 years of age with rapid height growth and moderate diameter growth until the trees are 75-100 years old.

WOOD AND BARK MORPHOLOGY

Wood

The sapwood of western larch, generally less than 1 inch wide, ranges from whitish to pale, straw-brown and the heartwood is a distinct russet or reddish brown in color. One of the heavier and harder softwoods, the wood is straight-grained and coarse-textured with a characteristic oily appearance and greasy feel. Growth rings are distinct, delineated by a pronounced generally very narrow and quite uniform band of darker latewood. The transition from earlywood to latewood is very abrupt with the former occuping two-thirds or more of the ring. Fiber tracheids, with occasionally spiral thickenings in the latewood, average 38-50 µm in diameter and 2.82-4.09 mm in length for specific samples. Longitudinal parenchyma are very sparse or wanting. Rays are fine, inconspicuous and of two types, uniseriate or rarely in part biseriate and fusiform. Ray tracheids are present in both. The usually uniseriate rays are numerous and 1-20+ cells in height. Fusiform rays, 2-3 seriate through the central thickened portion tapering to uniseriate margins and up to 20+ cells in height, are scattered with one or very rarely two transverse resin canals. Longitudinal and transverse resin canals are lined with thick-walled epithelial cells with occasional tylosoids in the heartwood area. Longitudinal canals, small and inconspicuous as sparse flecks confined generally to the narrow bands of latewood or as streaks along the grain on a tangential plane, have a maximum diameter of 135 (average 60-90) microns. Much smaller, the transverse canals, spaced at irregular intervals on the transverse surface, have diameters of less than 25 microns.

Bark

Western larch bark, thin and grey on young trees, becomes thick, reddish-brown and scaly with age, forming deep irregular fissures in very old trees. The thick outer bark provides good insulation against forest fires and can be removed from living trees without harm to the tree. Scales, outlined by the distinct reddish-brown periderm, on cross section, are nearly parallel to one another and are brittle and easily peeled off. The inner bark is rather narrow, usually about 0.1 inch thick, and light yellowish-brown in contrast to the outer bark. In the trees used in this study, the outer bark accounted for 80-90% of the total bark thickness by weight. Figure 20 illustrates a cross section of western larch inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

Bark of a young tree is composed of a layer of cutinized epidermal cells, 2-3 layers of small, compact and uniformly thickened cells, and a layer of large cells with thin walls and large cell cavities where canal formations appear. The periderm in young stems and branches is mainly thin-walled phellem and 1-2 layers of phelloderm merging into the cortex. The cortex is composed of ordinary cortex cells, large resin cells, vertical resin canals, and sclerenchyma cells. Sieve cells, parenchyma, rays and resin canals from the newly differentiated fusiform rays form the secondary phloem of the young tree.

In the mature bark, the periderm is developed rather uniformly, the main portions of two adjacent periderms running mostly parallel. The radial distance between two periderms is about 0.08 inch with a vertical extent about 1-1.5 inches and tangential dimensions of scales are about 0.5 inch according to Chang (1). Composed of 2-4 layers of phelloderm, a layer of phellogen, and usually 3-5 layers of thin-walled phellem cells, periderm cells on cross section are rectangular in shape and slightly larger than phloem parenchyma cells. Phelloderm cells are parenchymatous in nature and the cell walls occasionally become "lignified." Broad bands of thick-walled, strongly lignified cells often appear outside the layers of regular thin-walled, suberized phellem cells or alternate with them.

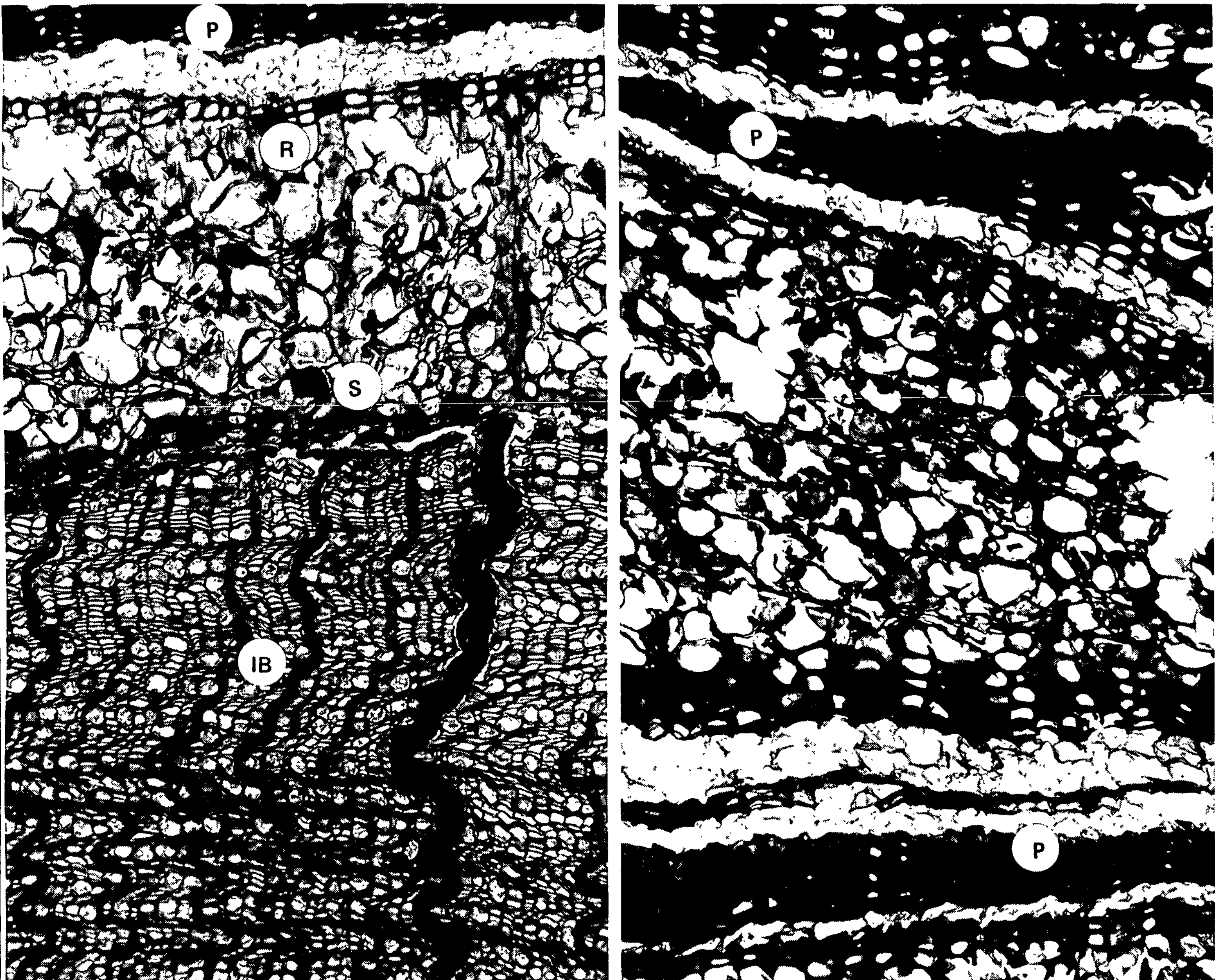


Figure 20. Cross Section of Western Larch. Photomicrograph on Left Shows Part of the Inner Bark (IB) and Rhytidome (R). Note Cross Section of Sclereidlike Fiber (S). Photomicrograph on Right is a Cross Section of the Outer Bark Showing Periderm (P) Layers. Magnification — 75X Left, and 110X Right

In the secondary phloem of the mature western larch, sieve cells are aligned in radial rows interrupted about every fifth cell by tangential lines of parenchyma and sporadically distributed sclereidlike fibers. Sieve cells are usually rectangular or slightly rounded on cross section, with tangential dimensions varying from 30-70 µm; radial dimensions, from 15-35 µm; and lengths, from 2.55-4.85 mm. Phloem parenchyma, aligned tangentially or sporadic, are about the same size and shape on cross section as the sieve cells, but usually radially expanded at the outer part of the bark. Rather uniform in cell wall thickness, individual cells vary from 70-180 µm in height and contain tanniferous substances and crystals of calcium oxalate. Sclerenchyma, due to the relatively short length and often branched shape, are referred to as sclereidlike fibers by Chang (1) and appear only very sporadically, about 0 to 5 per sq mm, and are usually absent in most parts of the inner bark. Their length varies from 0.8-1.9 mm, usually about 1.5 mm. Cell walls are thick with distinct laminate layers in the secondary wall.

Phloem rays are both uniseriate and fusiform. Uniseriate rays are usually 12 cells or 250 µm high with conspicuous erect ray margin cells. Fusiform rays vary in size and contain well-developed horizontal resin canals of thin-walled epithelial cells. Resin canals become conspicuously enlarged at the outer part of the inner bark and often closely aligned in a vertical row in the outer bark. The dilation of the fusiform rays and the expansion of the horizontal resin canals in the outer bark makes the transformation of the secondary phloem tissues conspicuous in the rhytidome. Parenchyma often enlarge and sieve cells are commonly obliterated in the outer bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIX summarizes the information available on wood and bark of western larch. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of western larch at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.50 appears appropriate for the wood of western larch. Our limited data show the heartwood and sapwood to be fairly close in specific gravity.

The specific gravity of the total (inner + outer) bark of western larch is considerably less than that of the wood. The inner bark appears to be slightly higher in specific gravity than the outer bark or else approximately

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

the same. Overall values suggested for use in species comparisons are 0.50 for wood and 0.37, 0.33 and 0.33 for inner, outer and total bark.

TABLE XIX

WESTERN LARCH SPECIFIC GRAVITY INFORMATION
(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
0.48						Isenberg (7)
0.48						IUFRO (6)
0.51						Besley (U.S.) (3)
0.55						Besley (Canada) (3)
0.48	0.38-0.54					Maeglin & Wahlgren (4)
0.51						Wood Handbook (15)
		0.43	0.35			Smith & Kozak (8)
0.51 (sapwood) 0.56 (heartwood)		0.36	0.32	0.32		IPC 3212-74
0.44 (sapwood) 0.52 (heartwood)		0.32	0.32	0.32		IPC 3212-78
0.54[a]						Isenberg (7)

[a]Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Extractives levels of 1.4% have been reported for the wood of western larch (see Table XX). Based upon information obtained from the literature and from the two trees sampled as part of this project, the bark of western larch can be expected to have an extractives level of 14.4%. This high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques.

TABLE XX

WESTERN LARCH ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	1.4	Isenberg (7)
Wood	1.4	Rydholm (12)
Bark	16.1	Harkin & Rowe (9)
Bark	10.0	IPC 3212-74
Bark	17.0	IPC 3212-78

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of western larch having an effect on the pulp are sieve cells. Western larch bark contains no sclereids but it does have a small amount of fiber. Chang (1) estimated that 67.1% of the tissue elements in the inner bark are sieve cells and 1.8% are sclereidlike fibers.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

The sclereidlike fibers are much like the fiber found in Douglas-fir. These types of cells have very thick walls and narrow lumens. The elongated fiberlike sclereids in western larch appear to be of questionable value in most pulp furnishes other than increasing yield since they are extremely stiff, would not fibrillate and would have low bonding strength.

As a check on pulp yield and the nature of the material produced from western larch, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXI summarizes the results of this investigation. Micropulping western larch bark resulted in a yield of 27-29% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells and all of the sclereidlike fibers. The on 150-mesh screen contained equal

TABLE XXI

WESTERN LARCH MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-74	3212-78	Remarks
Yield, % solids	27.0	28.5	
Fraction			
On 60 mesh, %	51.4	26.5	The fraction contained principally sieve cells (80-90%) with small percentages (5-10%) of sclerenchyma (fibers), thick-walled peridermal cells (<5%), and a trace (<1%) of thin-walled peridermal and parenchyma cells. The average arithmetic length of the sieve cells contained in the fraction was 2.23 mm (range 0.5-3.9 mm)
On 100 mesh, %	5.0	11.2	The fraction contained sieve cells (70-80%), thick-walled peridermal cells (20-30%), thin-walled parenchyma and peridermal cells (<5%) and a trace (<1%) of sclerenchyma (fibers)
On 150 mesh, %	6.4	10.2	The fraction contained thick-walled peridermal cells (30-40%), thin-walled parenchyma and peridermal cells (30-40%) and sieve cells (20-30%)
On 200 mesh, %	6.6	5.6	The fraction contained thick-walled peridermal cells (60-70%), thin-walled parenchyma and peridermal cells (30-40%) and sieve cells (<5%)
Through 200 mesh, %	30.6	46.0	The fraction contained a large percentage of thick-walled peridermal cells (80-90%) with a smaller percentage of thin-walled parenchymatous and peridermal cells (10-20%)

[a]Percentages given are on a dry weight basis.

proportions of thick-walled peridermal cells and thin-walled parenchyma and peridermal cells plus some sieve cells. The on 200-mesh and through 200-mesh screens contained principally thick-walled peridermal cells and some thin-walled parenchyma and peridermal cells. Figure 21 illustrates the type of material on the 60- and 150-mesh screens. The percentages of solids retained on each screen differed greatly between the two trees pulped. After investigation, it was determined that the two pulps were not handled identically during fiberizing and classification. Using an average of the two percentages given for each mesh would probably give a fairly accurate idea of what the results should be.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 28 grams of solids will result. Of this 28 grams, about 11 grams (11%) of sieve cells and 1 gram (1%) of sclereidlike fibers will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

As reported previously, a paper by Horn and Auchter (14) investigated the feasibility of pulping chips containing approximately 10% bark of a number of western species including western larch. They found that 0.2% more active cooking chemical as caustic soda and 0.2% more chlorine to bleach was needed for chips containing bark. Dirt levels could be lowered to an acceptable level by more efficient use of a centricleaner system and presence of bark in the pulp did not affect strength properties. Although digester yield from rough wood was less, the net gain per rough cord would be at least 4% higher for unbarked chips. They also felt that another 5-10% gain in yield could be realized because there would not be the wood loss usually incurred during barking. In our opinion, the net gain of 4% per rough cord would consist mainly of the less useful sieve cells.

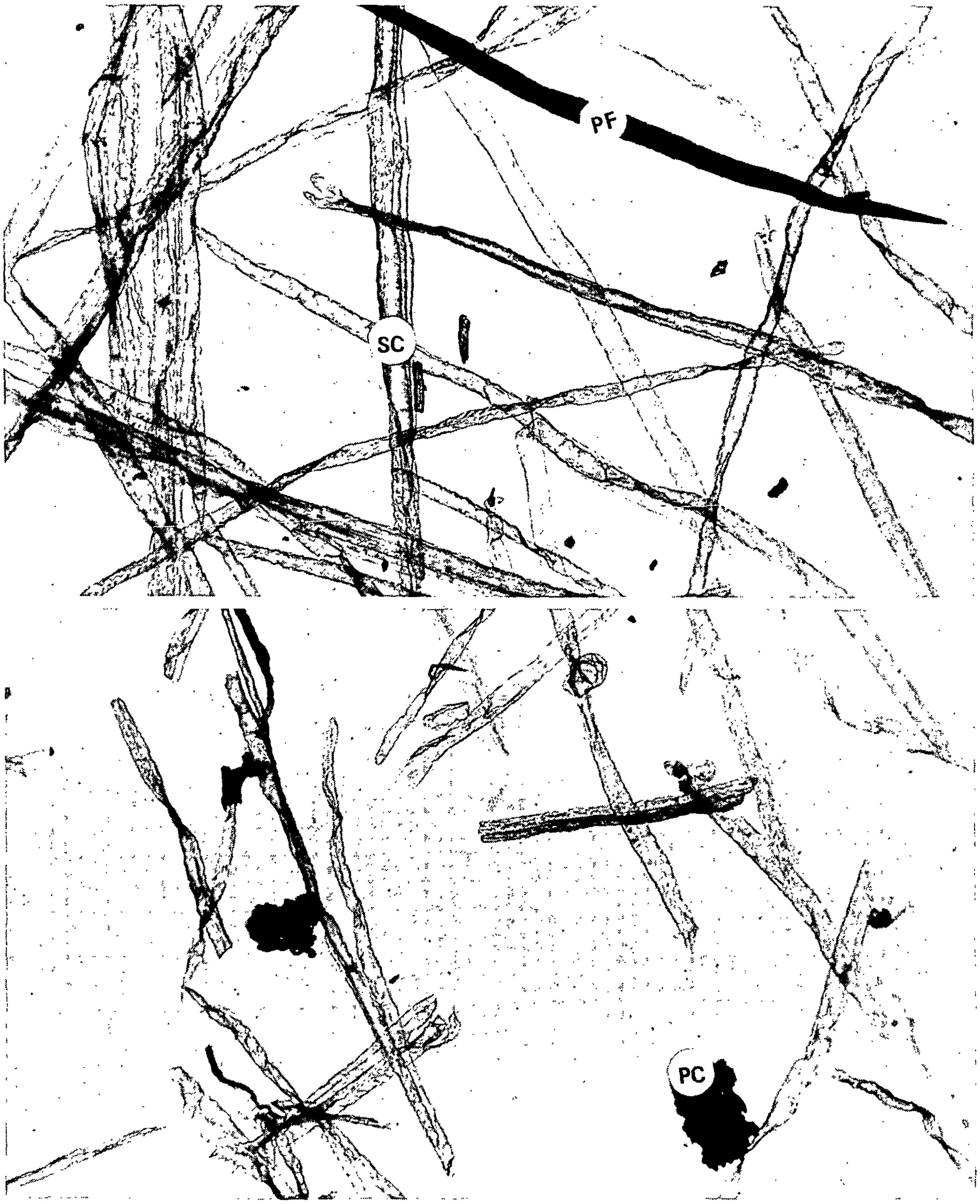


Figure 21. The 60-Mesh Screen (Top) Contained by Weight Principally Sieve Cells (80-90%). The 150-Mesh Screen (Bottom) Contained Thick-Walled Peridermal Cells (30-40%), Thin-Walled Parenchyma and Peridermal Cells (30-40%) and Sieve Cells (20-30%). Magnification — 75X. Symbols Illustrate Phloem Fiber (PF), Sieve Cells (SC), Parenchyma and Peridermal Cells (PC)

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for western larch samples collected July 25 (growing season) and October 12 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 22 illustrates the zone of failure for western larch during both the growing and dormant seasons. During the growing season, wood/bark adhesion was very low (1.2 kg/cm^2) and the failure zone occurred between immature xylary initials in the proximity of the cambium zone. Secondary thickening of the walls of these cells was still in process. During the dormant season, wood/bark adhesion increased to 4.4 kg/cm^2 and the break occurred in the secondary phloem between sieve cells and phloem parenchyma cells located approximately 1 mm from the cambium zone. Although the dormant season values are low, they appear to be valid values based on morphological examination.

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related

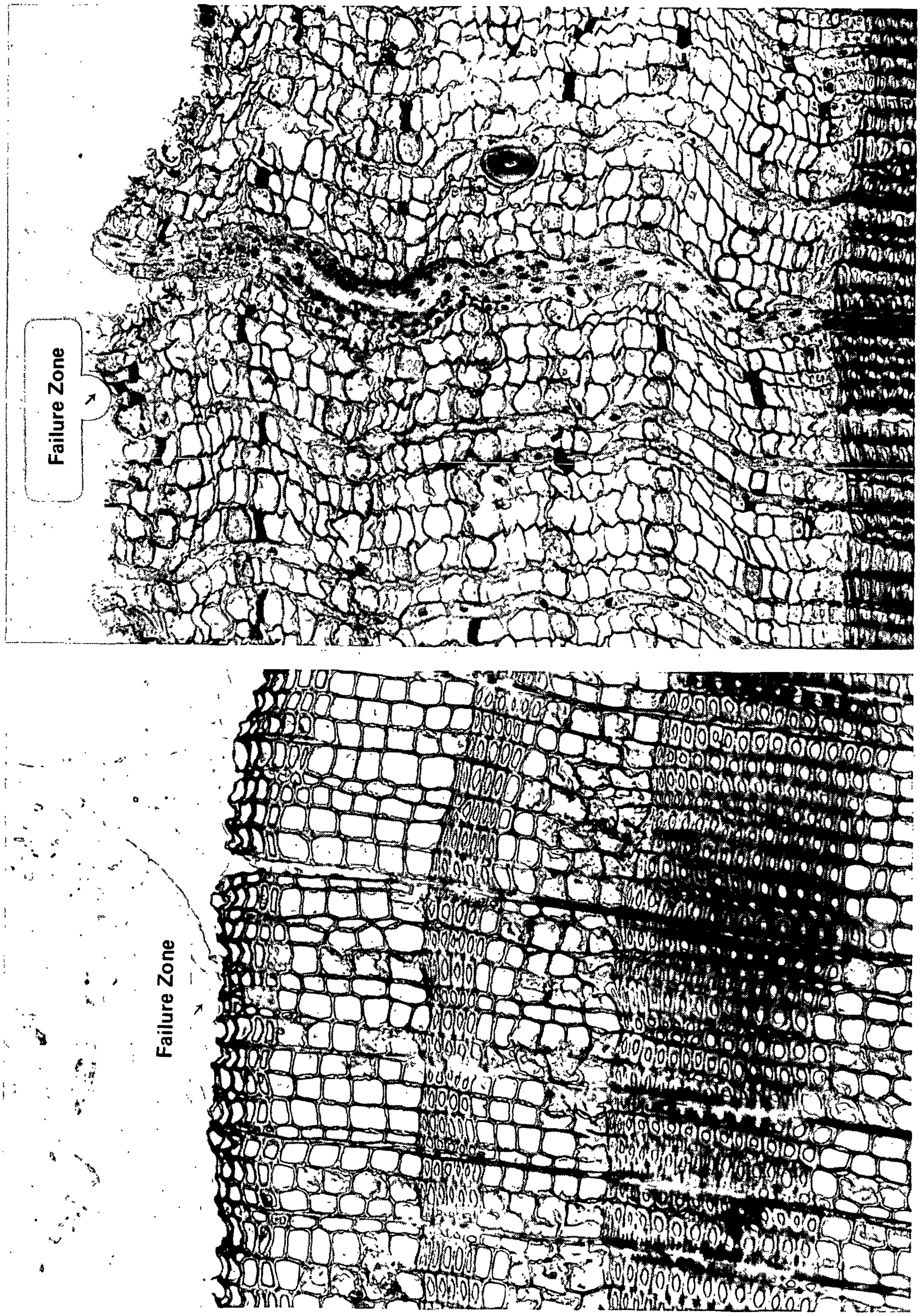


Figure 22. Illustrated are Zones of Failure for Western Larch. Failure During the Growing Season (Left) Occurred Between Immature Xylem Cells in the Proximity of the Cambium Zone. Secondary Thickening of the Walls of These Cells is Still in Process. During the Dormant Season, Failure Occurred in the Secondary Phloem Between Sieve Cells and Phloem Parenchyma Located Approximately 1 mm from the Cambium Zone. Magnification — 125X

to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. Adhesion values were low for western larch despite its containing a very modest amount of sclereid-like fiber. The amount of fiber is probably too small to make a real contribution to wood/bark adhesion and there are no other strong elements found in any quantity in the bark.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditions, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of western larch.

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF WESTERN LARCH[a]

Material	Strength	Toughness
Wood	--	0.28
Inner bark	4.5	0.12
Outer bark	4.4	0.10

[a]Determinations average of two different trees.

Bark strength values for western larch were moderate compared to other softwoods tested thus far. There were essentially no differences in bark strength values between the inner bark and outer bark of western larch. The toughness values for wood were relatively low although considerably greater than the bark values. The low toughness values obtained for wood make it appear that hammermilling or a similar technique might not work well on this species. The low toughness and moderate strength values for the bark are probably related to the large numbers of sieve cells and few fibers in western larch.

Toughness tests on a number of species, as reported by <u>Wood Handbook</u> (<u>15</u>), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test was done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. At 12% moisture content, <u>Wood Handbook</u> results show western larch wood with a tangential value of 340. In comparison, at 11-12% moisture content, values for loblolly pine were 260, slash pine — 320, jack pine — 240, lodgepole pine — 210 (green), ponderosa pine — 190 and Engelmann spruce — 180. The <u>Wood Handbook</u> results are somewhat anamolous for western larch compared to IPC values, as IPC values show western larch wood to be about as tough as lodgepole pine and weaker than the southern pines and jack pine. This is the first time this has occurred and, on the whole, the values have agreed very well.

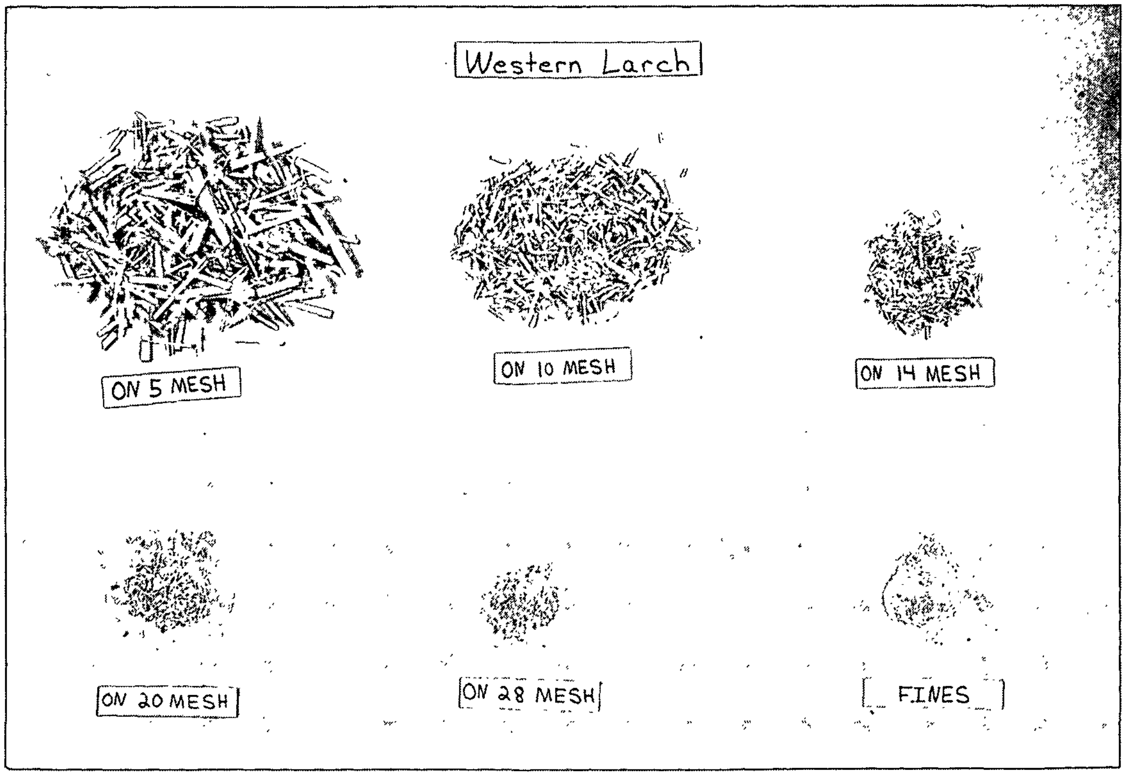
Summarized in Table XXIII are the results of the hammermilling tests run on western larch wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 6% wood loss and a 26% reduction in bark. This is a fairly low bark removal compared to many of the other softwoods investigated thus far, confirming the results obtained from the IPC toughness tests. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss is also doubled (40% bark removal and 12% wood loss). This additional 6% loss in wood might be acceptable in view of the increased amount of bark removed and the fuel value of the wood. Figure 23 illustrates the effect of hammermilling on wood and bark of western larch. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON WESTERN LARCH

Tree No.	Material	Fraction Retained on Standard Screen, %[a]						Remarks
		5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	
3212-74	Bark	28	34	14	7	7	10	Inner bark narrow and hard to distinguish although it appears more inner bark on larger screens
	Sapwood	56	31	7	2	2	2	
	Heartwood	46	41	7	3	1	2	
3212-78	Bark	24	33	16	8	7	12	Inner bark narrow layer and hard to distinguish although it appears more inner bark on larger screens
	Sapwood	65	27	4	1	1	2	
	Heartwood	50	37	7	3	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.



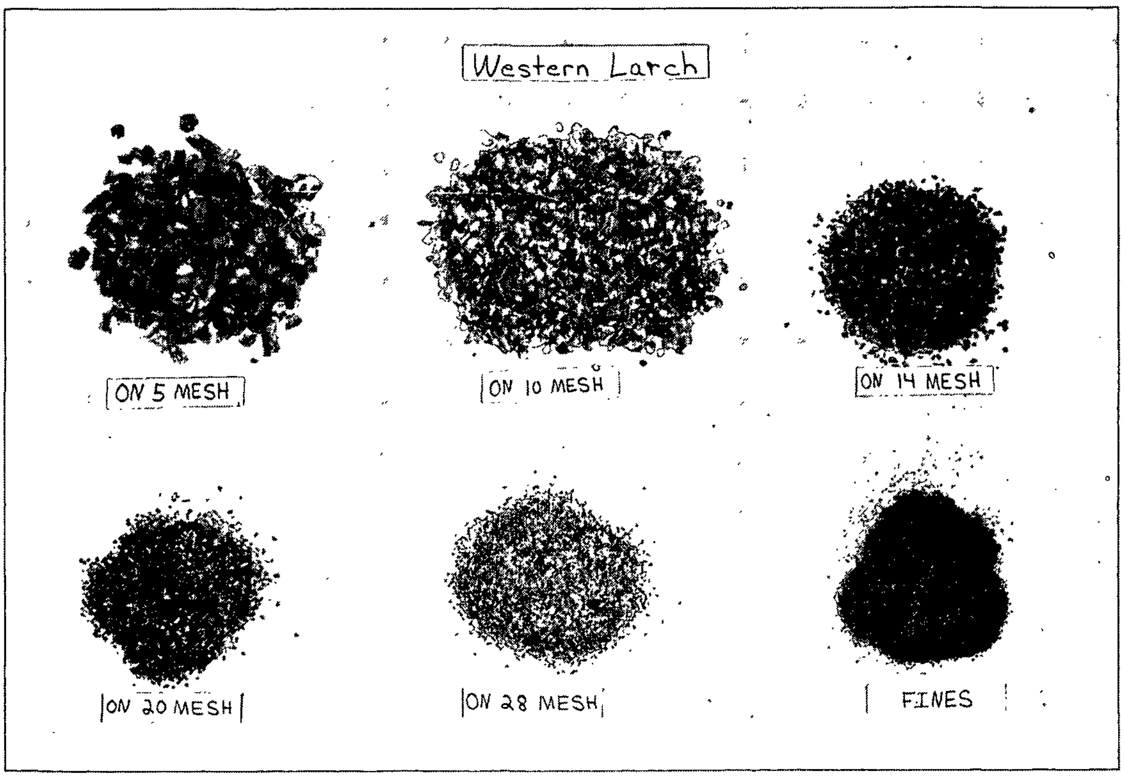


Figure 23. Illustrated is the Effect of Hammermilling on Western Larch Wood (Top) and Bark (Bottom)

made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 23 (16, 17). Summary Table XXVII compares bark strength, toughness and reaction to hammermilling of western larch to other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two western larch trees (IPC 3212-74 and IPC 3212-78) were used in making the determinations.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for both trees had a somewhat higher density than whole bark while the outer bark had approximately the same density as whole bark. It appears that outer bark would behave similarly to total bark under flotation conditions.

Figure 24 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that, at moisture contents of 60% or greater, most wood chips could be expected to sink (density greater than 1). Western larch bark, on the other hand, could be expected to float (density less than 1). Since the density of bark increases at a much slower pace than wood at increasing moisture contents, water flotation looks like a feasible technique for segregation of western larch wood and bark chips.

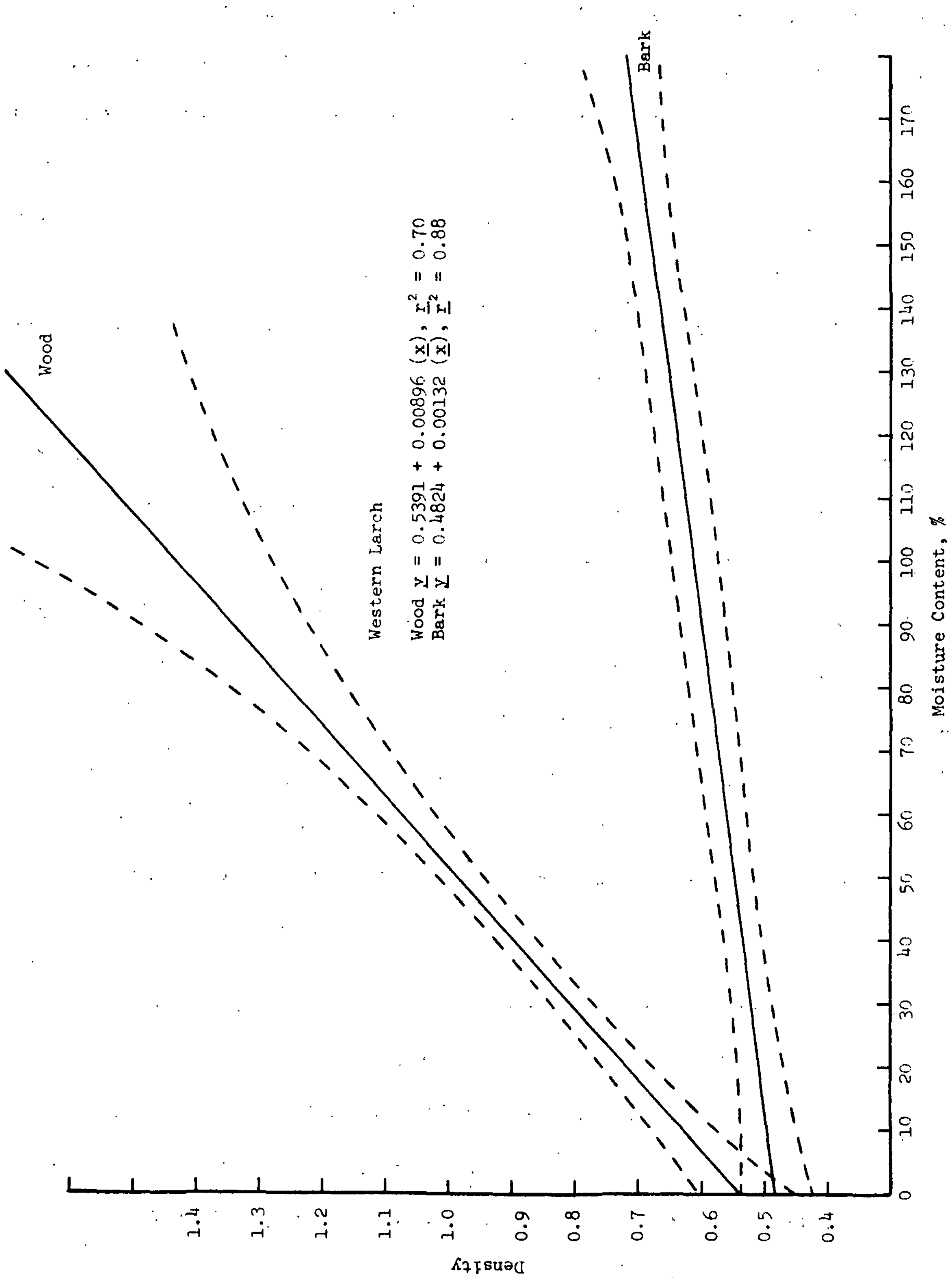


Figure 24. Illustrated is the Relationship Between Basic Density and Moisture Content for Western Larch. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximtely 20% (ovendry basis). Table XXIV summarizes the results for western larch. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content.

DATA INTERPRETATION

Western larch is one of the few softwood species with fiber in the bark. However, like Douglas-fir, the fiber is poor in quality. The sclereidlike fiber is extremely stiff, would not fibrillate and would have low bonding strength. For every 100 grams of bark that is pulped, about 11 grams of sieve cells and 1 gram of sclereidlike fiber will be produced. Again, the sieve cells would act as filler but would not contribute much to paper properties.

TABLE XXIV

SUMMARY OF DWELL TIME RESULTS FOR WESTERN LARCH[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-74 Bark	After 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-74 Sapwood	After 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-74 Heartwood	After 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-78 Bark	After 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-78 Sapwood	After 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-78 Heartwood	After 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

Western larch also has fairly high extractives (14.4%). Although there is some fiber in western larch, the high extractives and only modest amount of fiber probably make removal of at least part of the bark desirable. Dormant season adhesion values are low and reasonable separation through action of the chipper appears possible during most of the year.

Hammermilling western larch bark resulted in only a very modest reduction in bark levels (26% reduction in bark by retaining the material on a 14-mesh screen). However, hammermilling could be combined with screening as a method of quickly upgrading chip quality. Water flotation also looks promising as a segregation method with wood sinking and bark floating at moisture contents of 60% or greater. It is possible again that water flotation could be used with the screening and hammermilling technique for effective segregation, although the wet rejects would be less useful as fuel.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (18), Hooper (19), and Biltonen, et al. (20). Previously cited papers by Besley (3) and Smith and Kozak (8) contain information on moisture content of western larch and the previously cited paper by Harkin and Rowe (9) gives pounds of bark per cubic foot of wood by diameter classes. The potential of bark as fuel is briefly discussed in a paper by Grantham and Ellis (22).

BARK FUEL VALUE, ASH, CALCIUM, AND SILICA LEVELS

FUEL VALUE

Rising fuel prices have prompted a closer look at the use of bark as fuel. For many end products, removal of the bark is necessary and utilization of bark as fuel is a partial solution to disposal of bark waste.

Listed in Table XXV are the Btu values of the species investigated thus far, both in terms of Btu per ovendry pound and Btu per cubic foot. Although values are quite similar when figured on the basis of Btu per ovendry lb, the relative fuel value of the various species becomes more apparent when the specific gravity of the bark is taken into account and heating value is figured in terms of pounds per cubic foot. Also given in Table XXV are values found in the literature. In most cases, the values found in the literature have been converted to pounds per cubic foot for comparison with IPC values.

Chang and Mitchell (25) reported that the heating value of hardwood barks was lower than that of softwood barks. They found that the barks of all eight softwood species investigated had values greater than 8500 Btu per dry pound but nine of twelve hardwoods had lower values. However, hardwood barks, on the whole, are higher in specific gravity than softwoods and, when this is taken into account by calculating the values on a cubic foot basis, the fuel value of hardwood barks is generally greater than that of softwood barks.

Fuel value is extremely sensitive to moisture content. Green wood of most species has about 60% of the heat value of well air-dried wood. For instance, a pound of oven-dried red oak wood with a calorific value of 8600 Btu yields about 5700 Btu when air dried and about 3400 Btu when green (26).

TABLE XXV

BARK FUEL VALUES

Species	Total Sp.Gr.	Weight, lb/ft^3	Btu/lb o.d. wt.	Btu/ft^3	Literature Values, Btu, lb/ft^3 [a]
Quaking aspen	0.50	31.2	8,712	271,814	318,041 (27), 263,110 (25)
Sugar maple	0.54	33.7	8,426	283,956	299,572 (27), 246,044 (25)
White birch	0.56	34.9	10,332	360,587	371,160 (27), 329,247 (25)
Northern red oak	0.65	40.6	8,896	361,178	320,090 (28)
Southern red oak	0.70	43.7	8,371	365,813	349,250 (28)
Northern white oak	0.58	36.2	7,536	272,803	
Southern white oak	0.56	34.9	8,046	280,805	256,271 (28)
Eastern cottonwood	0.31	19.3	8,422	162,545	
Sweetgum	0.42	26.2	7,650	200,430	188,640 (28), 195,190 (25)
Loblolly pine	0.33	20.6	9,320	191,992	
Slash pine	0.35	21.8	9,327	203,329	196,244 (25)
Douglas-fir	0.41	25.6	9,962	255,027	252,595 (29)
Western hemlock	0.45	28.1	9,297	261,246	262,735 (29)
Engelmann spruce	0.51	31.8	8,830	280,794	265,816 (25)
Lodgepole pine	0.38	23.7	9,382	222,353	241,503 (25)
Ponderosa pine	0.35	21.8	9,616	209,629	
Western larch	0.32	20.0	8,825	176,500	164,080 (25)
White spruce	0.39	24.3	8,913	216,586	241,399 (27)
Balsam fir	0.40	25.0	9,339	233,475	281,190 (27), 221,525 (25)
Jack pine	0.41	25.6	9,393	240,461	299,155 (27), 224,282 (25)

[a]Literature cited [Chang and Mitchell (25)] values based on airdry samples with an average moisture content of 6% (range 4.8 to 6.7%).

ASH, CALCIUM, AND SILICA LEVELS

Listed in Table XXVI are percent ash, calcium and silica on an ovendry basis. Ash is the noncombustible part of the bark and needs to be removed, at least in part, after burning. According to Chang and Mitchell (25), a high percentage of ash tends to give lower heat of combustion values. Wood has a low ash content, generally less than 1% of dry weight (29). IPC ash values for bark ranged from 0.8% for loblolly and slash pine to 12.6% for northern white oak. Softwoods generally had lower ash values than did hardwoods. Also listed in Table XXVI are values obtained from the literature.

Calcium is one of the principal inorganic elements in bark. When bark is pulped, high levels of calcium can be expected to increase recovery furnace scaling problems. More rapid scaling increases furnace down time and reduces heat transfer. Low percentages of calcium in bark are therefore desirable. Trends were the same for percent calcium with loblolly and slash pine again the lowest of the species investigated (0.2%) and northern white oak the highest (5.2%). Also, as with percent ash, softwoods generally had lower values than did hardwoods.

Insoluble silicates are naturally occurring minerals that are commonly found in soils. They include not only extremely hard and abrasive types of minerals but silicon as an element in clay minerals of soils. Silica (SiO_2) levels are of interest because, in the form of minerals, they represent the principal acid insoluble fraction in bark and, as such, are expected to remain as one possible abrasive contaminant in pulps.

The SiO_2 levels reported in Table XXVI are levels from bark samples which have been carefully harvested and transported and represent SiO_2 levels in

TABLE XXVI

PERCENT ASH, CALCIUM AND SILICA IN BARK

Ovendry Basis

Species	Ash, %[a]	Literature Values, ash, %	Calcium, %	Silica, %
Quaking aspen	5.2	2.8 (25), 3.9 (27)	1.9	0.03
Sugar maple	8.3	6.3 (25), 5.0 (27)	3.0	0.19
White birch	2.4	1.5 (25), 1.7 (27)	0.7	0.06
Northern red oak	5.4	5.4 (25)	2.2	0.12
Southern red oak	6.5		2.6	0.14
Northern white oak	12.6	10.7 (25)	5.2	0.29
Southern white oak	8.2	10.7 (25)	3.4	0.42
Eastern cottonwood	6.2		2.5	0.18
Sweetgum	10.5	5.7 (25)	3.8	1.41
Loblolly pine	0.8		0.2	0.09
Slash pine	0.8	0.6 (25)	0.2	0.04
Douglas-fir	1.2		0.3	0.06
Western hemlock	1.7		0.3	0.04
Engelmann spruce	2.6	2.5 (25)	0.8	0.08
Lodgepole pine	2.2	2.0 (25)	0.6	0.16
Ponderosa pine	0.7		0.2	0.16
Western larch	2.4	1.6 (25)	0.6	0.26
White spruce	4.2	3.5 (27)	1.2	0.14
Balsam fir	3.4	2.3 (25), 2.6 (27)	1.0	0.10
Jack pine	1.3	1.7 (25), 2.1 (27)	0.3	0.14

[a]Ashed at 600°C.

bark relatively free from contaminating soil minerals. Some measure of silica levels (principally sand) that are added by harvesting and transporting could be obtained by comparing appropriately sampled and analyzed wood and bark samples from company operations with the relatively soil-free silica (SiO_2) levels reported in Table XXVI.

BETWEEN-SPECIES COMPARISONS

Between-species comparisons of bark characteristics provide a method for developing useful interrelationships and help improve our overall understanding of bark. Table XXVII (conifers) and Table XXVIII (hardwoods) provide a quick method of comparing the basic information available for the first 20 species investigated. Not only does the data assist in determining species in which the bark problems can be handled in a similar manner but, as more information becomes available, an increasing number of useful relationships between morphology, density, bark strength, wood/bark adhesion, ash content, fuel value, etc., are expected to become evident.

Between-species comparisons in Progress Report Four included a review of the information available for hardwoods. Since this report deals with four western conifers and no new information is available on the hardwoods, the comments that follow will be confined primarily to the conifers that have been investigated to date by Project 3212.

For the species investigated, most conifer barks were lower in specific gravity than the hardwood barks (Engelmann spruce and eastern cottonwood are exceptions). Conifer bark was generally similar or lower in specific gravity than associated sapwood (Engelmann spruce was an exception). Because of the lack of major differences in the specific gravity between the bark and wood of conifers, Engelmann spruce and western larch appear to be the only two conifer species in which bark could be segregated from the wood by water flotation with no additional preparation. Because the sink-float characteristics of these two species are opposite, segregation of chips from a chip mixture of the two species would not be feasible.

TABLE XXVII

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-Fir	Western Hemlock	Lodgepole Pine	Ponderosa Pine	Englemann Spruce	Western Larch
Specific gravity (o.d. wt./green vol.)											
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40	0.39	0.39	0.34	0.50
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45	0.38	0.35	0.51	0.33
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46	0.32	0.34	0.41	0.37
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45	0.45	0.35	0.52	0.33
Extractives, %											
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6	3.5	5.3	2.8	1.4
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7	15.7	15.7	24.4	14.4
Density at 100% moisture (green wt./green vol.)											
Wood	0.70	0.75	0.79	0.88	1.10	0.815	0.80	0.89-0.92	0.96	0.80	1.43
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85	0.74-0.95	0.62	1.14	0.61
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8	27.4	29.1	24.4	27.8
Usable bark fiber, %[a]	0	0	0	0	0	5	0	0	0	0	1
Sclereids remaining, %[a]	1.5	12.0	0	0	0	2	11	0	0	3	0
Fiber location[b]	--	--	--	--	--	IB-OB	--	--	--	--	IB
Sclereid location[b]	IB-OB	IB	--	--	--	IB-OB	IB-OB	--	--	OB	--
Wood/bark adhesion, kg/cm^2											
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6	2.2	5.0	3.4	1.2
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2	5.6	--	--	4.4
Bark strength, kg/cm^2											
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0	--	4.6	--	4.5
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--	2.4	4.9	4.2	4.4
Toughness											
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12	0.10	0.10	0.24	0.12
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10	0.08	0.08	0.16	0.10
Sapwood	0.34	0.42	0.34	0.54	0.54	0.58	0.28	0.28	0.26	0.26	0.28
Hammermilling[c]											
Bark removed, %	23	44	26	34	36	28	24	31	26	25	26
Wood loss, %	4	6	5	6	5	4	3	4	4	4	6

[a]Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60 and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b]Major proportion located in either the inner bark (IB) or outer bark (OB).
[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

TABLE XXVIII

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULPWOOD SPECIES

Characteristic	Quaking Aspen	Eastern Cottonwood	Sweetgum	Sugar Maple	White Birch	Northern Red Oak	Southern Red Oak	Northern White Oak	Southern White Oak
Specific gravity (o.d. wt./green vol.)									
Wood	0.38	0.38	0.44	0.59	0.49	0.56	0.60	0.64	0.67
Total bark	0.50	0.31	0.42	0.54	0.56	0.65	0.70	0.58	0.56
Inner bark	0.40	0.29	0.51	0.69	0.57	0.53	0.68	0.65	0.70
Outer bark	0.55	0.32	0.36	0.49	0.54	0.71	0.70	0.52	0.44
Extractives, %									
Wood	3.0	1.4	2.6	1.0	4.0	4.5	4.8	2.4	4.6
Bark	15	7.9	10.2	6	17	11	11.6	7.2	8.6
Density at 100% moisture (green wt./green vol.)									
Wood	0.79	0.84	0.84	1.24	1.01	1.06	1.25	1.30	1.38
Bark	1.15	0.81	0.87	1.08	1.16	1.18	1.39	1.05	1.13
Pulp yield, % (bark)	33.8	35.4	34.9	33.9	36.3	28.4	30.7	35.4	36.6
Usable bark fiber, %[a]	10	9	5	3	0	5	4	3	3
Sclereids remaining, %[a]	1	<0.1	--	0.2	0.7	0.2	--	--	--
Fiber location[b]	IB	IB	IB	IB	--	IB	IB	IB	IB
Sclereid location[b]	IB	--	IB	IB	IB	IB	IB-OB	IB-OB	IB-OB
Wood/bark adhesion, kg/cm^2									
Growing season	6.4	4.4	10.2	5.8	5.1	2.5	5.4	4.8	--
Dormant season	11.4	13.5	15.3	10.1	12.0	8.4	8.2	7.8	7.2
Bark strength, kg/cm^2									
Inner bark	9.0	17.7	8.1	1.4	1.6	2.1	3.6	4.6	4.7[d]
Outer bark	4.9	4.2	5.2	4.7	9.8	4.6	3.4	3.2	--
Toughness									
Inner bark	0.22	0.14	0.20	0.25	0.10	0.13	0.11	0.16	0.12
Outer bark	0.10	0.11	0.11	0.10	0.10	0.18	0.14	0.10	0.09
Sapwood	0.45	0.38	0.28	1.20	0.68	0.93	0.55	0.62	0.98
Hammermilling[c]									
Bark removed, %	34	18	32	29	38	34	46	37	38
Wood loss, %	5	5	7	5	6	10	6	5	3

[a]Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60 and 100-mesh screens. The percentage given is the yield based on whole bark samples.

[b]Major proportion located in either the inner bark (IB) or outer bark (OB).

[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

[d]Test mistakenly performed on total bark.

Conifer bark, with the exception of Douglas-fir and to a minor extent, western larch, contains no fiberlike elements. As a result, when pulped, the conifer barks examined to date are not expected to produce useful fiber that will contribute to the strength of the paper and board being produced. Also, there is some evidence that the high amount of thin-walled cells (sieve cells and parenchyma cells) produced when high levels of bark are pulped, could result in paper machine drainage problems.

There has been no consistent pattern with regard to the level of bark extractives with the exception that the levels in the bark are from about three to eight times as high as in the wood. Most conifer barks have higher levels of extractives than hardwood barks. Slash and loblolly pine are the exception with the extractive levels of only 8.4 and 8.5%. Engelmann spruce and balsam fir have the highest levels of extractives. Even with these two species, because of the relatively thin bark involved, pitch problems are not expected to be serious unless, as the result of concentrating large amounts of bark from screening procedures, high levels of bark are pulped.

Wood/bark adhesion during the growing season was low and very similar for all species investigated (except sweetgum) and, quite consistently, the zone of failure occurred in the cambium zone or the newly formed, nonlignified wood fibers adjacent to the cambium zone. Dormant season adhesion was, as expected, higher than growing season adhesion and the failure zone usually occurred in the partially mature sieve and parenchyma cells of the inner bark, just outside of the cambium zone. Dormant season wood/bark adhesion tends to be slightly higher for the hardwoods than for conifers and, in certain instances, seems to be associated with the presence of large numbers of phloem fibers in the inner bark.

Mechanical treatment of bark continues to look promising as a method of upgrading low quality chips high in levels of bark. Toughness (and very likely, bark strength) varies with species but is consistently lower for bark than for wood. Toughness differences suggest hammermilling or a similar mechanical treatment could be used to reduce the size of bark particles and allow removal by screening. Correlations between hammermilling and bark strength and toughness so far are quite low. For the hardwoods, the best correlation seems to be between bark specific gravity and bark removal (high specific gravity gives high removal). The same type of correlation does not seem to exist for the conifers investigated. In the case of the conifers, bark thickness and, in particular, the thickness of the outer bark seems to be a factor. Bark removal by hammermilling has been less effective for conifers than hardwoods and this suggests some type of mechanical action which differs considerably from hammermilling needs to be investigated. Chip shredding is a technique which was developed more than 20 years ago and, although not widely employed, appears to be worthy of further consideration. Chip shredding has been used mainly with conifers and the kraft pulping process. At least two pieces of commercial equipment have been used in shredding investigations (Jones Vertiflex and Sprout-Waldron milling machine)*. Shredded wood chips have been described as giving increased yields, lower chemical consumption and either reduced cooking temperature and/or lower cooking times (30, 31). Shredding is reported to not have affected pulp strength properties of sulfate and bisulfite pulps. Some reduction in tear has been reported for acid sulfite pulps. The procedure that needs to be investigated would include the following steps: (1) dry screen to concentrate the bark in the small chip fraction, (2)

*The Jones Vertiflex is manufactured by the Jones Division of Beloit Corporation and the Sprout-Waldron milling machine is produced by Sprout-Waldron and Company, Inc.

shred the chip fractions high in bark with the hope that the lower toughness and shear strength of the bark will result in a major reduction in bark particle size versus a minor reduction in wood chip size, (3) dry screen again to remove the bark and wood fines (use for fuel), and (4) pulp the upgraded chips.

Bark ash content and calcium in particular is of importance because of its apparent influence on recovery furnace scaling problems. Levels of ash (and calcium) in the barks of conifers are quite consistently less than in hardwood bark. White spruce and white birch are exceptions. Calcium levels range from about 0.2% in slash, loblolly and ponderosa pine to 5.2% in northern white oak. Since the levels in the bark are about 10-15 times as high as in the wood of most hardwood pulpwood species, pulping of whole-tree chips can be expected to increase recovery furnace scaling problems.

The fuel values of the bark of pulpwood species are summarized for the first time in this report. The ovendry Btu values for hardwoods vary more than for conifers. Our data for hardwood bark confirms Chang and Mitchell's (25) observations and indicate that there is a negative correlation between ash content and ovendry Btu values. This relationship is less evident for the conifers investigated. Both hardwood and conifer barks, when the Btu values are converted to a cubic foot basis, demonstrate fairly major differences. These differences are due to bark specific gravity differences. Values range from 162,500 for cottonwood to 365,800 Btu/cubic feet for southern red oak. Western larch had the lowest values of the conifers tested (176,500 Btu/cubic feet) while Engelmann spruce had the highest value (280,800 Btu/cubic feet).

PLANS

To date, the bark of 20 pulpwood species has been characterized, including quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); white spruce, balsam fir, jack pine, eastern cottonwood (Report Three); southern white oak, northern white oak, southern red oak, sweetgum (Report Four); and lodgepole pine, ponderosa pine, Engelmann spruce and western larch (Report Five). Twelve species remain to be characterized. The next report will include longleaf pine, shortleaf pine, Virginia pine and red pine. The report is scheduled for completion around the middle of April.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

dbh. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Paratracheal. Said of xylem parenchyma which occurs at the edge of the annual ring, around the vessels, but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Scalariform. Like a ladder.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elonged, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Suberized. Transformed into cork.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylose. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

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APPENDIX

TABLE XXIX

SAMPLE TREE INFORMATION

Species	Tree No.	Age, yr	Height, ft	dbh, inch	Location
Lodgepole pine	3212-73	31	40	7.4	Idaho
	3212-76	85	50	8.0	British Columbia
	3212-81	85	45	8.1	Idaho
	3212-89	70	84	9.5	British Columbia
Ponderosa pine	3212-72	28	39	8.6	Idaho
	3212-79	100	58	10.0	Oregon
	3212-84	26	40	8.0	Idaho
	3212-90	100	35	8.0	Oregon
Engelmann spruce	3212-75	41	36	7.4	Idaho
	3212-77	73	60	8.0	British Columbia
	3212-83	53	65	8.2	Idaho
	3212-87	80	65	9.0	British Columbia
Western larch	3212-74	135	69	8.2	Idaho
	3212-78	87	63	10.5	British Columbia
	3212-82	103	70	8.5	Idaho
	3212-88	70	72	9.5	British Columbia

TABLE XXX

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2 Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Lodgepole pine	2.2	5.6
Ponderosa pine	5.0	9.6
Engelmann spruce	3.4	12.5
Western larch	1.2	4.4
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4
Southern red oak	5.4	8.2
Northern white oak	4.8	7.8
Southern white oak	--[a]	7.2
Sweetgum	10.2	15.3

[a]Growing season adhesion not measured.

TABLE XXXI

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm² Inner Bark	Bark Strength, kg/cm² Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	7.4	--
Jack pine	--	0.07
Balsam fir	0.06	--
Lodgepole pine	--	2.4
Ponderosa pine	4.6	4.9
Engelmann spruce	--	4.2
Western larch	4.5	4.4
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2[a]
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6
Southern red oak	3.6	3.4
Northern white oak	4.6	3.2
Southern white oak	4.7[b]	--
Sweetgum	8.1	5.2

[a]Strength low, test samples failed during preparation, data based upon a single test.

[b]Bark strength measured on total bark rather than inner and outer bark.